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ABSTRACT

This manual on modern gas and arc welding is one of a series of power mechanics texts and visual aids on the servicing of automotive and off-the-road agricultural and construction equipment. Materials provide basic information with illustrations for use by vocational students and teachers as well as shop servicemen and laymen. The eight sections focus on (1) Gas Welding, (2) Arc Welding, (3) Oxygen and Arc Cutting, (4) Brazing and Soldering, (5) Metal Surfacing, (6) Design of Welded Units, (7) Properties of Metals, and (8) Welding Safety. Each part concludes with test questions. Answers to the test questions and a glossary are appended. (A supplementary 35mm slide set is also available--see availability note.) (LRA)

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Welding

JOHN DEERE

FOS

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TO THE READER

PURPOSE OF THIS MANUAL

The main purpose of this manual is to train the reader so that he can understand modern gas and arc welding. A full story is also given on cutting, brazing, soldering, surfacing, design of welds, properties of metals and welding safety. For the novice, this manual is a training guide; for the journeyman a reference. The manual is written in a simple form using many illustrations so that it can be easily understood.

WHAT IS "FUNDAMENTALS OF SERVICE"?

This manual is part of a series of texts and visuals called "Fundamentals of Service", or "FOS". These materials are basic information in power mechanics for use by teachers as well as shop servicemen and the layman. All types of modern equipment are covered — both automotive and off-the-road. Emphasis is on theory of operation, diagnosis, and repair.

Answers to "Test Yourself" questions, at the end of each chapter, appear at the end of this manual on pages 121 and 122.

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GAS WELDING / PART 1

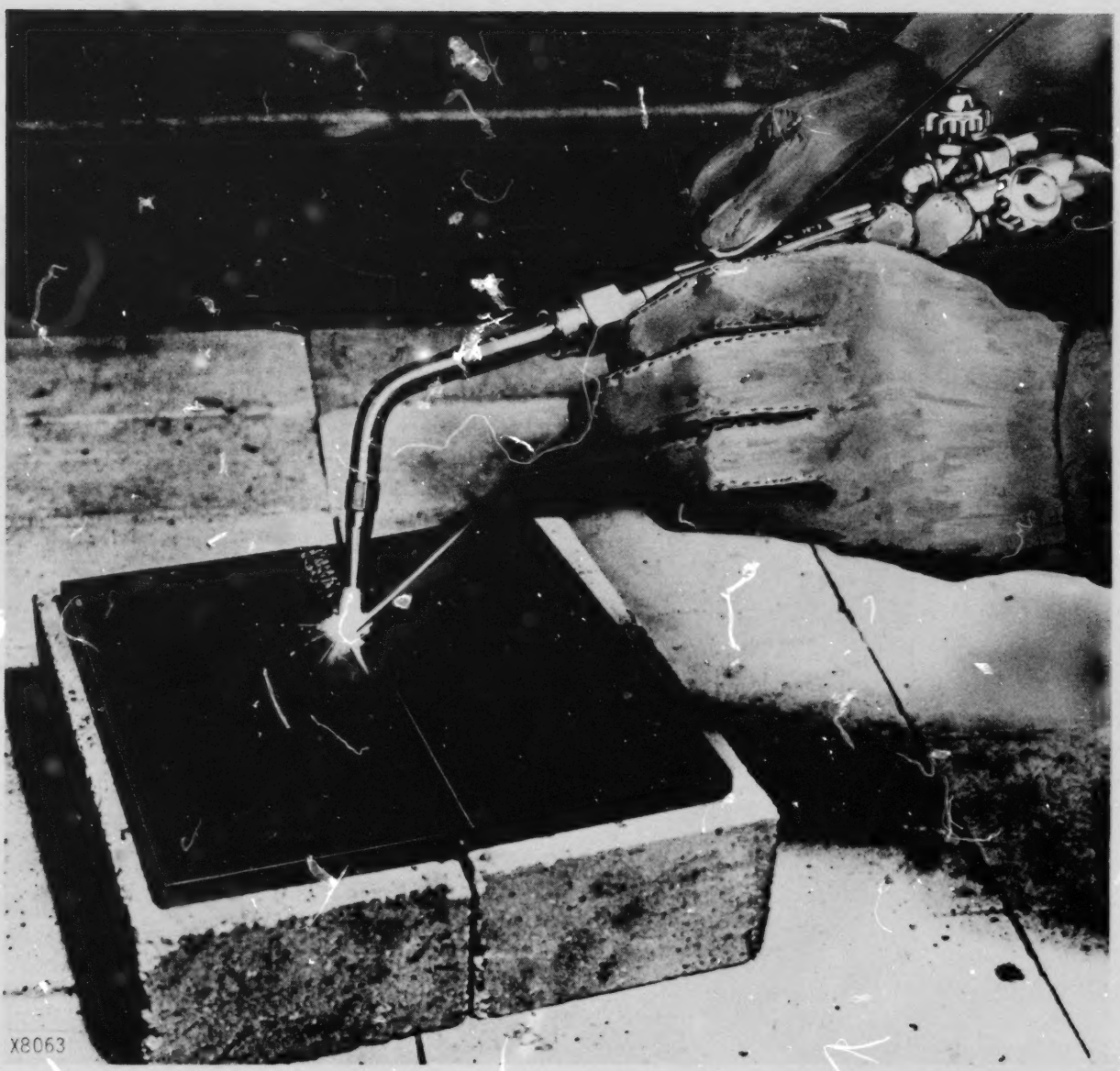

Fig. 1 — Gas Welding

INTRODUCTION

In **gas welding**, two metals are joined by melting or fusing their adjoining surfaces. This is done by directing a gas flame over the metals until a molten puddle is formed. A filler rod may also be melted into the puddle to help the two metals run together and form one piece.

The energy for gas welding comes from the combustion of a fuel with oxygen or air (Fig. 2). The most popular fuels are acetylene, Mapp gas, and hydrogen.

Gas welding is *slower* and *easier to control* than electric arc welding. This makes it popular in smaller welding shops for general maintenance work, welding metals of low melting point, and for operations such as brazing, soldering, and metallizing.

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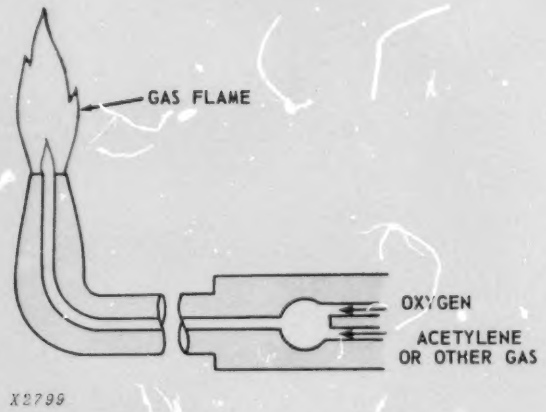

Fig. 2 — Basic Principle Of Gas Welding

OXY-ACETYLENE WELDING

The oxy-acetylene flame is probably the most widely used for gas welding because of its higher flame temperature. The flame is generated by burning a mixture of acetylene and oxygen. A ratio of 2½ oxygen to 1 acetylene produces a very hot flame of about 5800°F (3172°C).

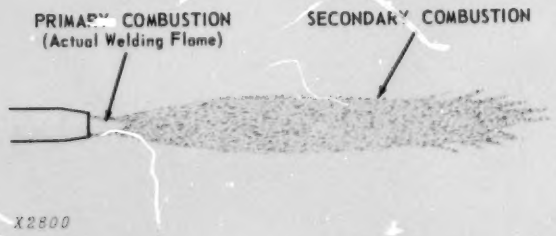

Fig. 3 — Oxy-Acetylene Flame

Combustion occurs in two stages as shown in Fig. 3. *Primary combustion*, which is the actual flame for welding, is the *inner cone*.

Secondary combustion is the *outer flame* and serves as a protective shield to prevent the air from contaminating the molten puddle as well as preheating the welding operation.

The primary flame results when oxygen and acetylene are mixed in the welding torch in a one-to-one ratio. This mixture flowing from the torch tip burns to form the inner cone when one volume of acetylene combines with one volume of oxygen to produce two volumes of carbon monoxide and one volume of hydrogen.

The carbon monoxide and hydrogen produced by the first reaction combine with oxygen in the atmosphere to form the secondary flame.

Thus a complete combustion of acetylene results from one volume of oxygen provided by the torch and 1½ volumes provided from the surrounding atmosphere.

EQUIPMENT

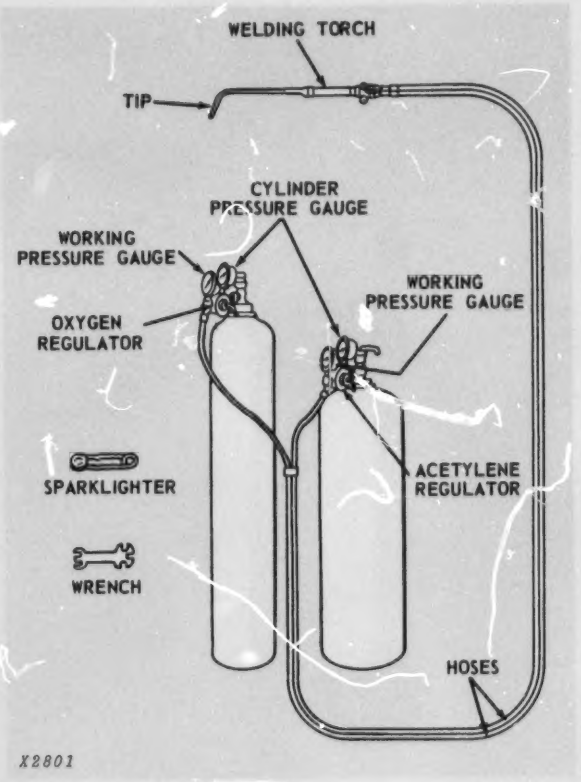

Fig. 4 — Oxy-Acetylene Welding Equipment

The following equipment is needed for oxy-acetylene welding:

- **Cylinders of oxygen and acetylene**
- **Pressure regulators**
- **Welding torch**
- **Hoses**
- **Welder's clothing**

Figs. 4 and 5 show this basic welding equipment. Now let's look at each item in detail.

Fig. 5 — Oxy-Acetylene Welding Outfit

CYLINDERS

Oxygen and acetylene cylinders are made from seamless drawn steel and tested very carefully. Sizes of cylinders are based on the cubic feet (cubic meters) of gas they contain. The three common sizes of oxygen cylinders are 244, 122, and 80 cu. ft. (6.75, 3.5, and 2.25 m³). Acetylene cylinders are made to hold 300, 100, and 60 cu. ft. (8.5, 2.75, and 1.75 m³).

Cylinders are equipped with a safety device to permit the gases to drain slowly in the event that heat raises the pressure beyond the safety load of the cylinder. Since gases expand when heated and contract when cooled, the safety device is a must.

The flow of oxygen from the cylinder is controlled by a high-pressure valve which is opened and closed by turning a hand wheel. The hand wheel must be turned slowly to permit a gradual pressure load on the regulator and opened as far as the valve will turn to get full gas pressure.

Acetylene cylinders are packed with a porous material saturated with acetone. The acetone absorbs large quantities of acetylene under pressure without changing the nature of the gas itself. This is necessary because free acetylene cannot be stored in cylinders since it becomes dangerously unstable when under pressure in a free state. (Actually, acetylene should never be used beyond a 15 pound (100 kPa) pressure.)

The cylinder valve on acetylene cylinders is opened with a special wrench. The valve should be opened to not more than one and one-half turns. A slight opening is advisable since it permits closing the valve in a hurry in case of an emergency.

When the volume demand of gas is high, especially for continuous operation over a long period of time, the oxygen and acetylene cylinders are attached to separate manifold systems. The gas in each system flows into the main stream and is controlled by a single master regulator.

Oxygen and acetylene cylinders are usually placed on a two-wheel cart to facilitate moving wherever welding is to be done. If cylinders are to be used at a permanent work station, be careful to chain them so they cannot be overturned accidentally.

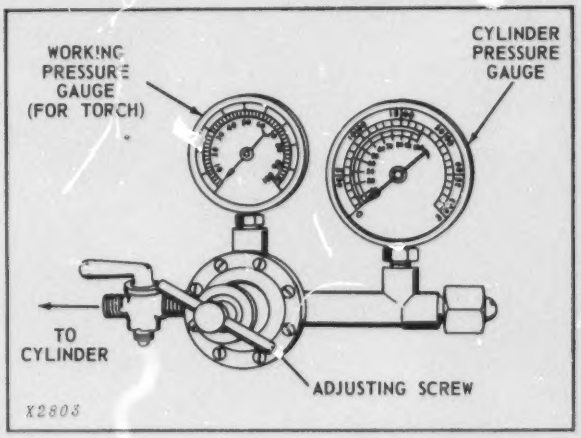

Fig. 6 — Regulators For Gas Pressures In Cylinders (Oxygen Regulator Shown)

REGULATORS

Oxygen and acetylene regulators are fastened to the cylinders. Their function is to reduce cylinder gas pressure to suitable values for welding.

For example, if an oxygen cylinder has a pressure of 1800 psi (12 400 kPa) and a pressure of 10 psi (70 kPa) is needed at the torch, the regulator must maintain a constant pressure of 10 psi (70 kPa) even if the cylinder pressure drops down to 500 psi (3450 kPa).

Both oxygen and acetylene regulators have two gauges (Fig. 6). One gauge tells the actual pressure in the cylinder and the other shows the working or line pressure used at the torch.

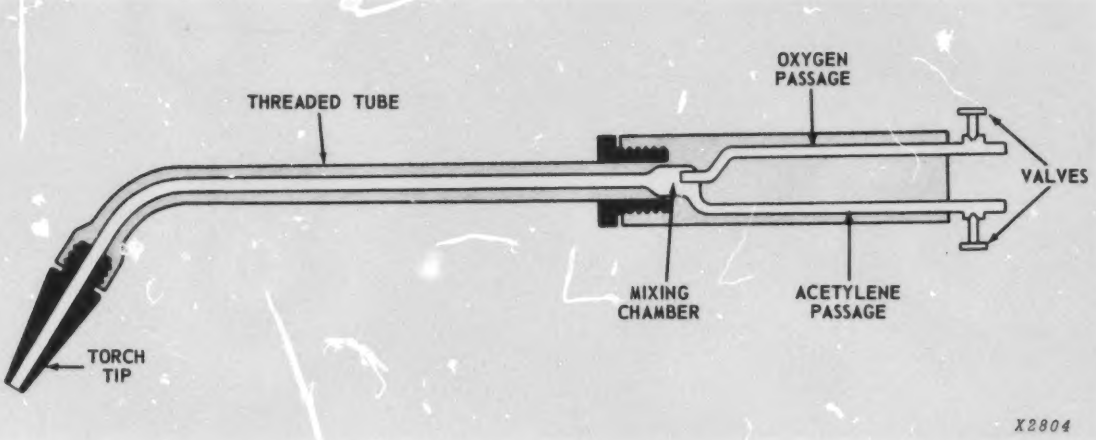

Fig. 7 — Welding Torch

Gas flow from a cylinder is regulated by an adjusting screw. This screw must always be released before a cylinder valve is opened; otherwise, the tremendous pressure of the gas in the cylinder is forced on the working pressure gauge which may damage the regulator.

Torch Operating Pressures

Tip Number	Thickness Of Metal (Inches)	(mm)	Oxygen Pressure psi	kPa	Acetylene Pressure psi	kPa
00	1/64	0.4	2½	17	1	7
0	1/32	0.8	2½	17	1	7
1	1/16	1.6	2½	17	1	7
2	3/32	2.4	5	34	2	14
3	1/8	3.2	7½	52	3	21
4	3/16	4.8	10	70	4	28
5	1/4	6.4	12½	86	5	34
6	5/16	8	15	103	6	41
7	3/8	9.5	17½	120	7	48
8	1/2	12.7	17½	120	7	48
9	5/8	15.9	18¾	130	7½	52
10	3/4 & up	19 & up	22½	155	9	62

**Pressures are with torch adjusted for neutral flame — used in most welding jobs.*

WELDING TORCH

The essential elements of a welding torch are a mixing chamber where the two gases are brought together and mixed, two needle control valves which control the flow of oxygen and acetylene, hose connections, and welding tip. See Fig. 7.

Different sizes of tips can be inserted in the mixing chamber to permit welding a range of metal thicknesses. The size of a tip is indicated by the diameter of its orifice which is usually designated by a number. Manufacturers of welding equipment provide charts to show the normal operating pressures for various tip sizes. See the table at left.

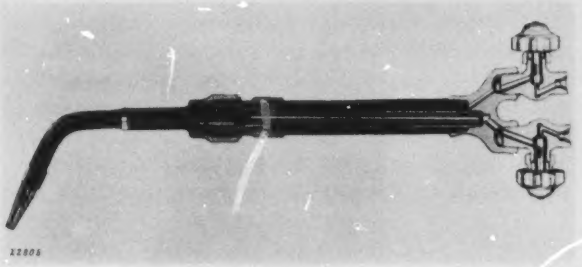

Fig. 8 — Typical Welding Torch

HOSE

Special non-porous hose is used to convey oxygen and acetylene from the cylinders to the torch. To prevent a mix-up, the oxygen hose is either green or black in color and the acetylene hose is red. Acetylene hose connections have left-hand threads while oxygen hose connections have right-hand threads.

WELDER'S CLOTHING

The operator must wear *protective goggles* while doing oxy-acetylene welding. The flame and molten metal emit ultraviolet and infrared rays and both could possibly cause eye injury if viewed at close range. Goggles also protect the eyes from glare and, most important, *flying sparks*. The goggle lenses must be tinted, not clear.

Fire-resistant gloves should also be used for most welding. Heavy clothing or aprons are also suggested.

PREPARING TO WELD

Before welding, be aware of the rules below for safety, cleaning, and bevelling.

SAFETY

Observe all **safety precautions** when you are preparing to weld. The prime rules are:

1. Be sure the work area has a cement or masonry floor.

2. Keep all combustible materials at a safe distance.

3. Do not use gloves or other clothing which contain oil or grease.

4. Keep firefighting equipment handy at all times.

NOTE: For complete safety rules, see Part 8, "Welding Safety."

CLEANING METAL TO BE WELDED

Clean the metal joints to be welded of all rust, scale, paint, dirt — and especially oil. Also be sure the metals are dry.

NOTE: Any foreign material which gets into the molten metal will change the resulting metal and may weaken it.

BEVELLING METAL JOINTS

Bevel the adjoining metal before welding it — except on very thin work.

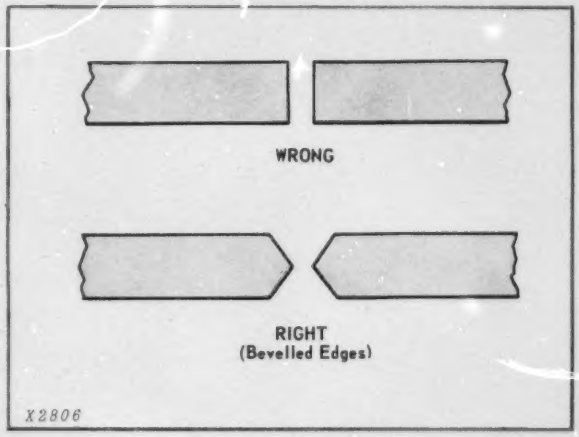

Fig. 9 — Bevelling Metal Joints Before Welding

On work less than one-fourth inch (6.4 mm) thick, bevel the edges to be welded at a 45 degree angle (Fig. 9). For work thicker than one-fourth inch (6.4 mm), bevel the edges at a 60 degree angle.

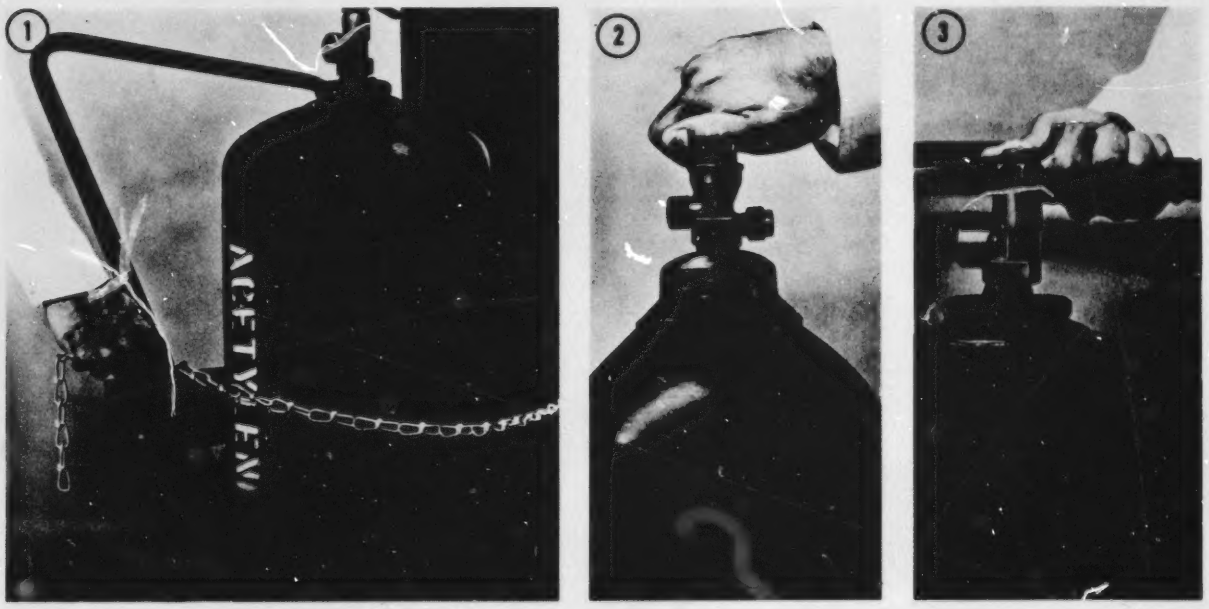

Fig. 10 — Setting Up Cylinders

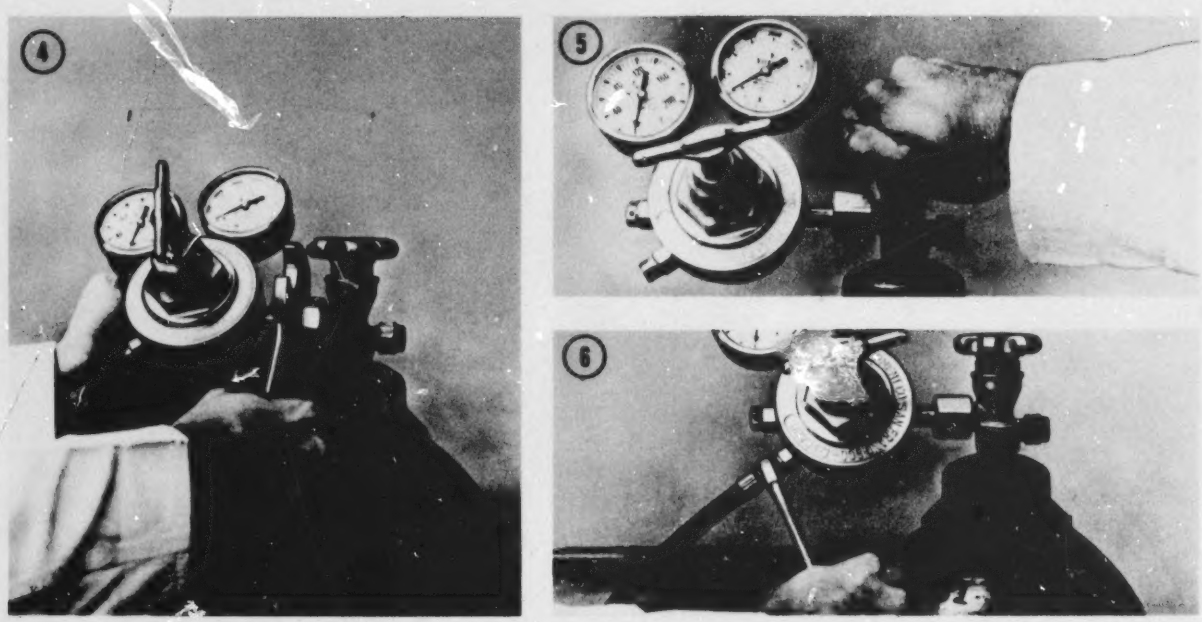

Fig. 11 — Setting Up Regulators

SETTING UP CYLINDERS

To set up new welding equipment, use the following numbered steps.

1. Place the oxygen and fuel gas cylinders together where they are to be used and secure them from falling (1, Fig. 10).

2. Unscrew the valve protection caps (2, Fig. 10). Put the caps away safely as they must be replaced on the empty cylinders before they are returned.

NOTE: Examine the cylinder valve threads. Wipe off any accumulation of dirt with a clean cloth to be certain no dirt will enter the regulator. (Cloth cannot have even a trace of oil or grease on it).

3. Slightly open (called "cracking") the oxygen and fuel gas cylinder valves to make sure they do not stick and to blow out any dirt or dust lodged in the valve (3, Fig. 10). Close the valve.

SETTING UP REGULATORS

4. Be sure that the regulator inlet connection is absolutely clean and free of all traces of dirt, grit, grease, etc. Attach the oxygen regulator to the oxygen cylinder valve using an open end wrench (Fig. 11). Do not use excessive force but tighten the regulator connection nut firmly.

NOTE: Be sure the regulator adjusting screw is in the "out" position. The adjusting screw is turned counterclockwise to release the tension.

5. Open the oxygen cylinder valve SLOWLY so the high-pressure regulator gauge needle will move up slowly until approximately 2000 psi (13 790 kPa) pressure is registered (if the cylinder is full). *Never stand directly in front or back of a regulator when an oxygen cylinder valve is opened. Always stand to one side.* After full pressure has been reached, open the valve completely.

If the valve leaks, immediately close it again and notify the supplier.

NOTE: Never use force on a cylinder valve to either open or close it. If the valve will not open or close by hand, notify the supplier and have the cylinder replaced.

Connect the fuel gas regulator in the same manner as you did the oxygen regulator.

NOTE: Open an acetylene cylinder valve only one complete turn — never more than 1½ turns.

6. Connect the oxygen hose (green) to the outlet of the oxygen regulator. The oxygen hose has right-hand thread connections. Turn the adjusting screw on the regulator clockwise or "in" until a reading of 5 psi (35 kPa) shows on the low pressure gauge. Allow the oxygen to escape until you are sure the hose is clean on the inside.

New hose may have talcum powder in it to protect the hose lining while in storage. Dust, dirt, and especially talcum powder, if left in the hose, may enter the small gas passages in the torch and plug them or cause a flashback.

Connect the fuel hose (red) to the fuel gas regulator outlet. The fuel has left-hand thread connections. Blow out the hose in the same way as you did the oxygen hose. **Remember that fuel gas will burn. Keep it away from open flames as you are blowing out the hose.**

SETTING UP TORCH

7. Connect the free ends of the oxygen hose (green) and fuel hose (red) to the welding or cutting torch you are to use. See Fig. 12. (Torch connections are normally marked "oxy" or "fuel".)

8. Select the tip or nozzle size that is suitable for the job you are to do. Refer to the Welding Tip Selection Charts furnished by the manufacturer.

9. Tighten the welding tip into the torch. Be sure that any sealing rings are in place. Tighten the tip only hand tight unless the manufacturer specifies otherwise.

10. Partially open the torch oxygen valve and adjust the oxygen regulator until the pressure corresponds to that listed for the tip you have selected.

11. Close the torch oxygen valve. Partially open the torch fuel valve and adjust the regulator pressure, using the chart as you used it for the oxygen pressure. Close the fuel valve.

NOTE: Observe that the regulator pressure rises slightly when the torch valves are closed. That is the reason for setting the regulator at required pressure with the valve open. All pressures in welding and cutting charts are **flowing** *pressures with the torch valves open.*

This is the time to check for leaks in the system — before operation. Follow the manufacturer's instructions.

OPERATING THE TORCH

12. Hold the torch in one hand and the sparklighter in the other (Fig. 13). *Don't use matches.*

13. Open the torch fuel valve approximately ½ turn and ignite the acetylene. Point the flame away from persons, the cylinders, or any flammable materials.

14. Keep opening the torch fuel valve until the flame stops excessive smoking and leaves the end of the tip about one-eighth of an inch (3.2 mm), then reduce slightly to bring flame back to the tip.

15. Open the torch oxygen valve until a bright inner cone appears on the flame. The point at which the feathery edges of the flame disappear and a

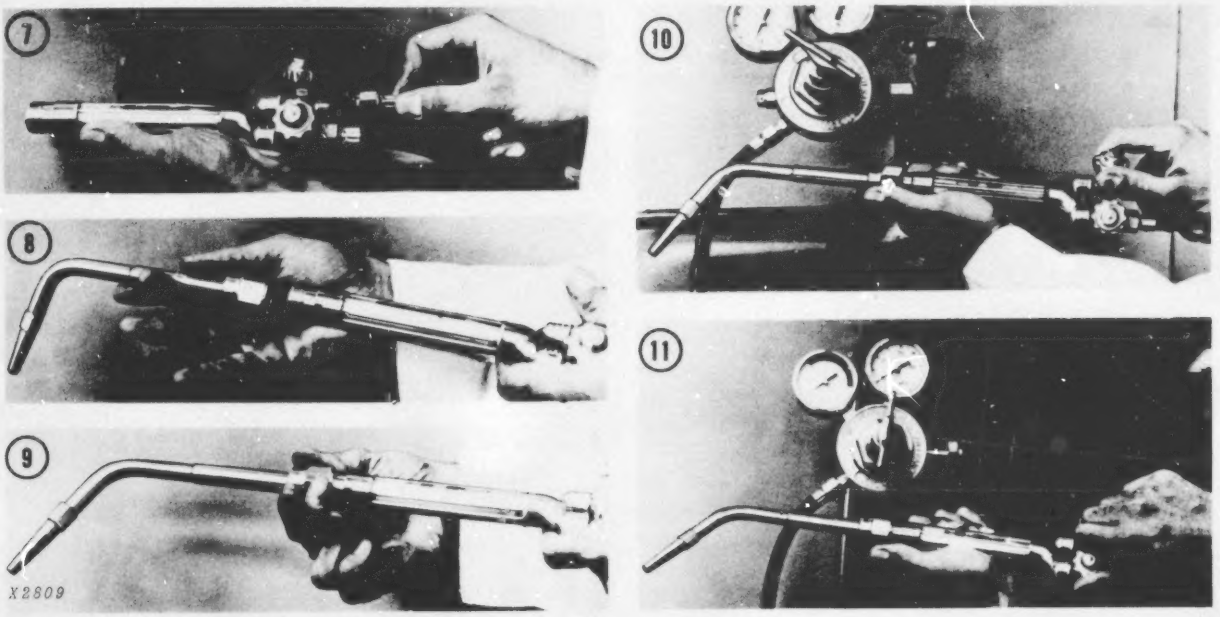

Fig. 12 — Setting Up Torch

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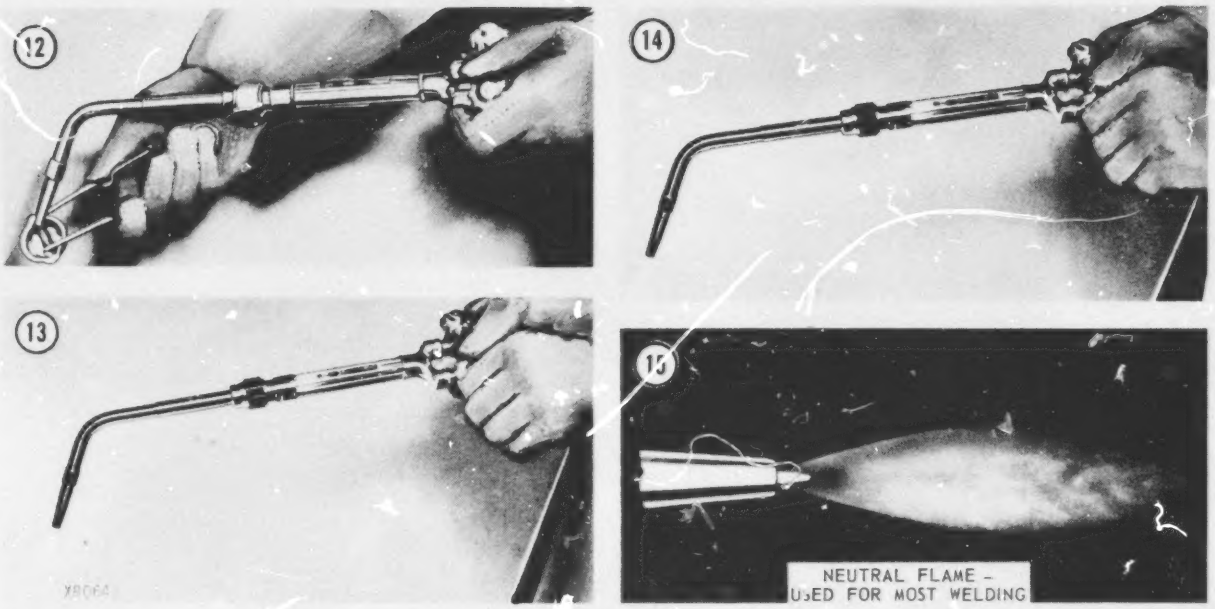

Fig. 13 — Operating The Torch

sharp inner cone is visible is called the **Neutral Flame.** Keep adjusting the torch oxygen valve back and forth until you are sure what a neutral flame looks like.

Fig. 14 — Carburizing Flame

The **Carburizing Flame**, shown in Fig. 14, is the flame you have before reaching the Neutral Flame. It is distinguished by its long carburizing feather. This flame is caused by an excess of acetylene.

An **Oxidizing Flame** is the flame that has an excess of oxygen beyond the Neutral Flame. It is a pale blue color without the clearly defined inner cone of the "Neutral Flame" shown in Fig. 13 (No. 15) above.

The neutral flame is used for most welding because it does not burn or carburize the metal.

The three flames are compared in Fig. 15.

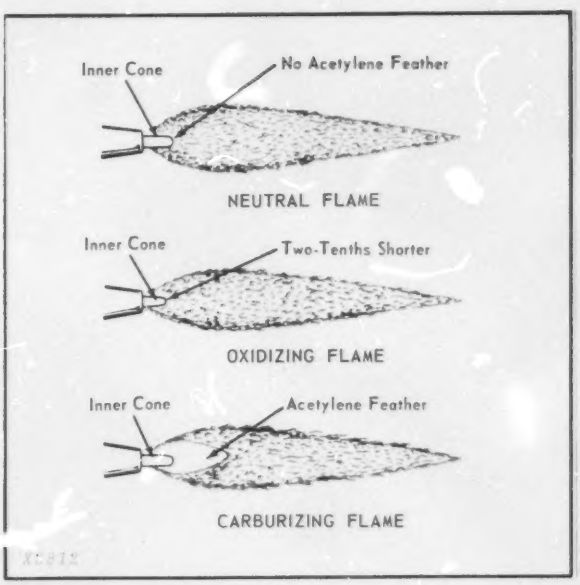

Fig. 15 — Comparison Of Three Flames

HOW TO WELD

Actual fusion of metal is achieved by moving the torch along the seam with the inner cone of the flame over the metal. The neutral flame has approximately a 1 to 1 oxygen-acetylene ratio. When the amount of oxygen is increased the flame is oxidizing. A carburizing flame develops when there is an excessive amount of acetylene.

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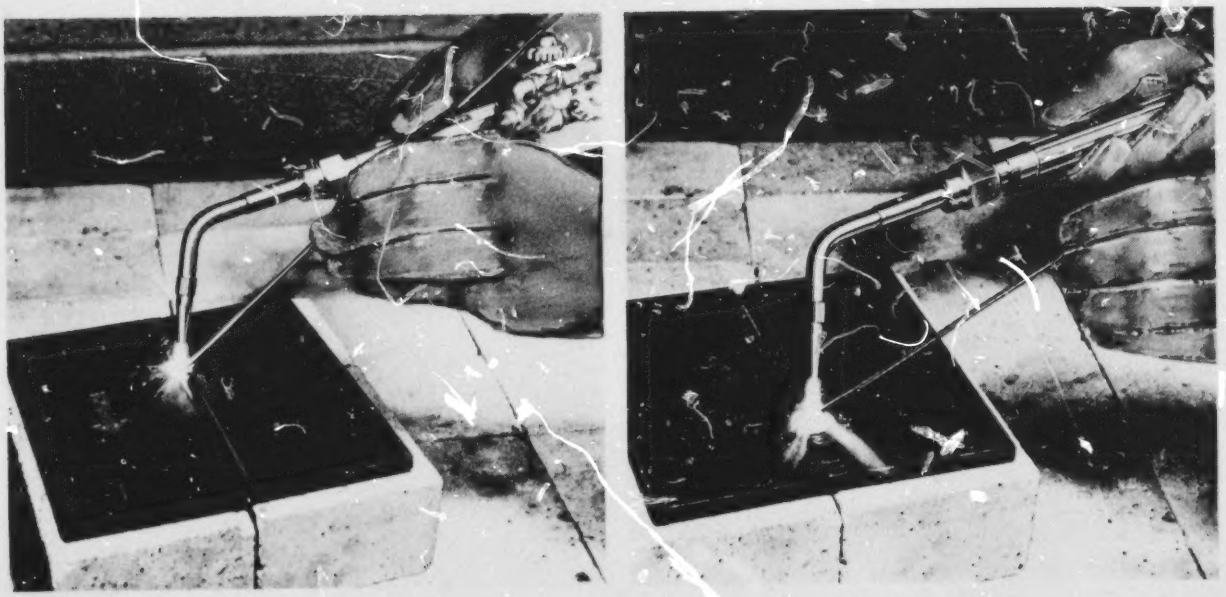


Fig. 16 — How To Weld — Two Methods

A flame can also be made soft or harsh by varying the gas flow. If the flow of gas is too low for a given tip size, the flame will not fuse the metal properly and will be sensitive to backfire (popping). Too high a gas flow produces a high-velocity flame that blows the molten metal from the puddle.

The welding torch can be operated in one of two ways:

- **Forehand welding**
- **Backhand welding**

FOREHAND WELDING is performed with the torch tip pointed forward in the direction in which the weld progresses and the rod precedes the flame (Fig. 16).

In BACKHAND WELDING the tip is pointed back toward the weld which has been deposited and the filler rod is interposed between the flame and the weld (Fig. 16).

Generally, the forehand method is best for welding thin materials of ⅛ inch (3.2 mm) or less in thickness, since there is better control of the weld puddle and smoother welds are possible.

The backhand technique is usually recommended for metals that are heavier than ⅛ inch (3.2 mm) because sound welds can be made at a greater speed.

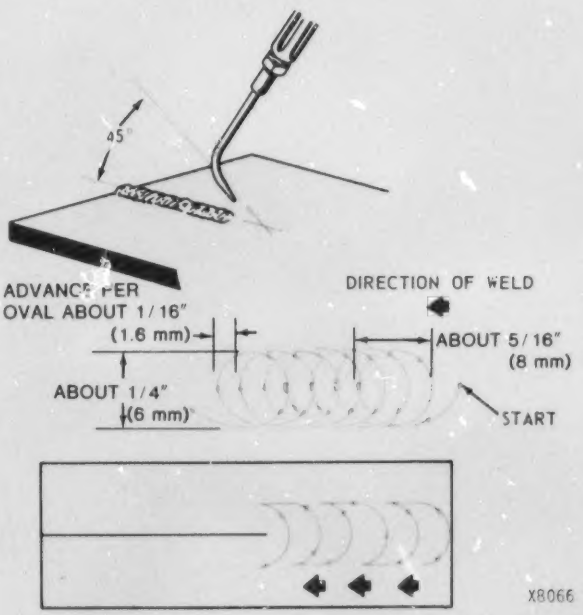


Fig. 17 — Position And Motion Of The Torch For Welding

The torch is always held at an angle of approximately 45° with the completed part of the weld (Fig. 17). As the torch is moved over the weld seam using the forehand method, it is often rotated in a circular or semi-circular motion as shown.

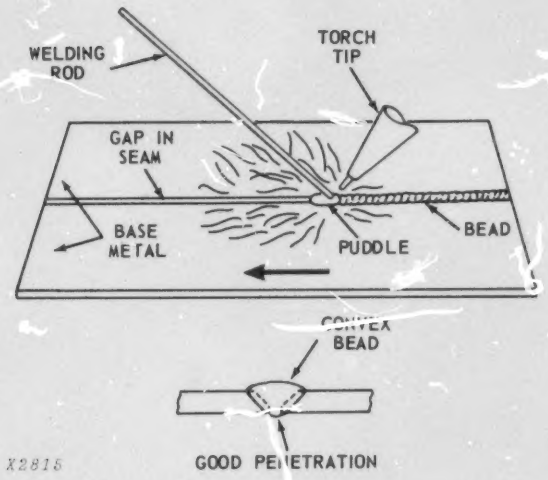


Fig. 18 — Position Of The Welding Rod

A *filler rod* of the same composition as the base metal is used in welding most types of joints. The rod is held at about the same angle as the torch but slanted away from the torch. See Fig. 18. The diameter of the rod should be equal to the thickness of the base metal. If the rod is too large, the heat of the molten pool will be insufficient to melt the rod. If the rod is too small, the heat cannot be absorbed by the rod and a hole is burned in the plate.

As the molten puddle is carried forward along the seam, the rod is dipped in and out of the molten metal. When the rod is not in the puddle, the tip is kept just inside the outer envelope of the flame.

Try not to stop in the middle of the weld as the "break" will be difficult to hide.

GOOD AND BAD WELDS

A good weld will usually have an even, slightly convex shape and will just penetrate the complete joint as shown in Fig. 19.

WELDING HINTS

1. Keep the puddle small.

2. Hold the rod in the puddle, away from the edges.

3. Concentrate the flame in the puddle and around the rod to preheat the plates ahead of the weld.

ALLOWING FOR CONTRACTION AND EXPANSION OF METAL

All metals expand when heated and contract when cooled. When welding steel plates of fairly small size, you must allow for closing of the joint opening as the welding progresses.

When two metal plates are welded in a butt joint, the following occurs:

As the weld proceeds along the joint, the metal shrinks in cooling from the molten state and tends to pull the two pieces of metal together. This shrinkage may cause the edges to lap one over the other, or warp the metal.

The operator may prepare the metal for the expansion and contraction which occurs during welding by:

1. Fusing (or *tacking*) the ends of the two pieces of the metal together before welding as in Fig. 20, A. This method will produce some internal strain, but will keep the ends sufficiently in line to enable the

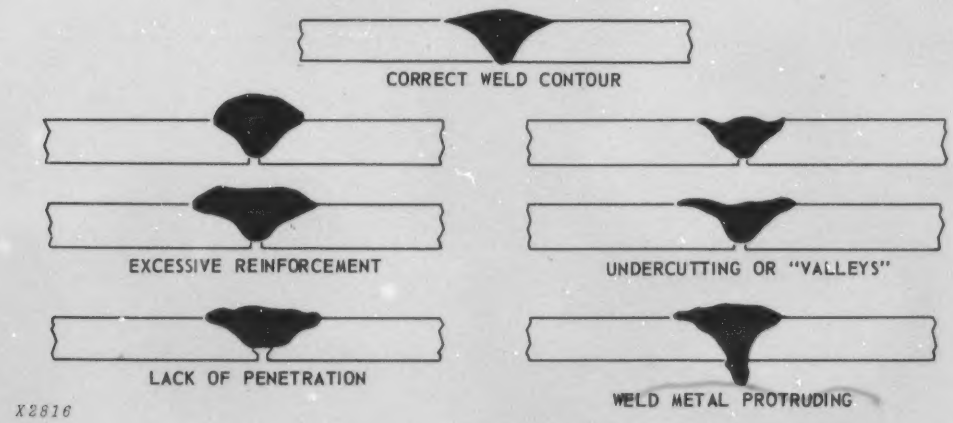
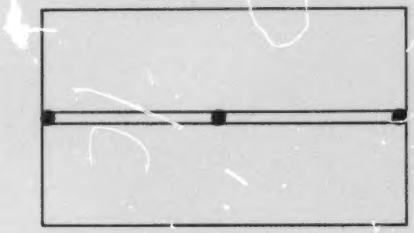
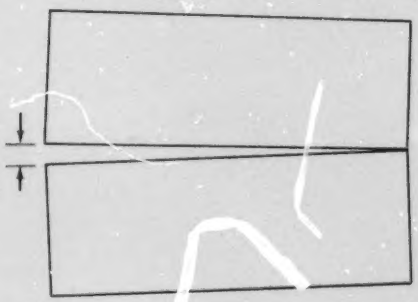


Fig. 19 — Good And Bad Welds

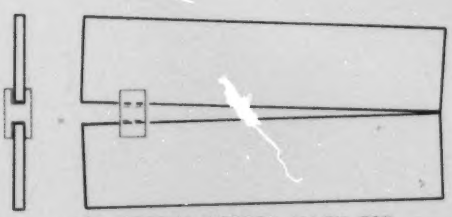
operator to make a good weld. Tacking each inch or so along the joint is popular practice.



(A) TACKING TWO PIECES TOGETHER BEFORE WELDING



(B) ALLOWANCE WHICH SHOULD BE MADE FOR CONTRACTION



(C) SPECIAL WEDGES ALLOW FOR CONTRACTION WHEN WELDING LONG PIECES

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Fig. 20 — Allowing For Contraction And Expansion Of Metal Plates When Welding

2. *Tapering* the gap between the two pieces of metal to allow for contraction as shown in Fig. 20, B. The approximate contraction is from ⅛ to ¼ in. per foot (3.2-6.4 mm per 300 mm) of length of the metal (the wider the puddle, the greater the contraction).

3. Using especially prepared *wedges* which may be placed between the two pieces of the joint to prevent the contraction of the metals as the weld cools as in Fig. 20, C. This method is more generally used with long joints.

4. *Clamping* the metal in a heavy fixture to reduce movement.

MELTING POINTS OF METALS

Know the melting points of the metals you are welding. When welding two different metals, be sure to heat the one having the higher melting point first to prevent destroying the other.

Melting Points Of Metals (°F — °C)		
Platinum	3200°	1779°
Iron, wrought	2900°	1612°
malleable	2500°	1372°
cast	2400°	1317°
pure	2760°	1517°
Steel, mild	2700°	1483°
medium	2600°	1428°
hard	2500°	1372°
Copper	1950°	1055°
Brass	1800°	983°
Silver	1750°	955°
Bronze	1700°	927°
Aluminum	1175°	636°
Antimony	1150°	622°
Zinc	800°	427°
Lead	620°	327°
Babbitt	500-700°	260-371°
Solder	500-575°	260-302°
Tin	450°	232°

The chart above tells you when different metals will melt.

Remember — The oxy-acetylene flame is 5800° F. and will rapidly heat anything it touches directly under the flame tip.

For more information, see Part 7, "Properties of Metals."

STOPPING WORK

When welding is to be stopped, close either the torch oxygen valve or the torch acetylene valve first — then the other valve.

If the oxygen valve is closed first, a popping noise may occur and soot may be detected after the valves are closed. However, by closing the acetylene valve last, the flame is observed as it is

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extinguished. If a small flame lingers at the end of the tip, a slight leak is present in the torch that should be repaired.

If the acetylene valve is closed first, the popping and soot is eliminated but leaks may not be detected.

When the welding is to be stopped for considerable periods of time such as during lunch hour or overnight, the cylinder valve should be closed and all gas pressures released from the regulators. Follow the steps listed below.

1. Close the oxygen cylinder valve.

2. Open the torch oxygen valve to release all pressure from the hose and regulator.

3. Turn "out" on the pressure adjusting screw of the oxygen regulator.

4. Close the torch oxygen valve.

5. Close the acetylene cylinder valve.

6. Open the torch acetylene valve to release all pressure from the hose and regulator.

7. Turn "out" on the pressure-adjusting screw of the acetylene regulator.

8. Close the torch acetylene valve.

Closing the cylinder valve and then opening the torch valve relieves all pressures in the regulator and hose line. After the gauge readings (both gauges) have reached zero, the pressure adjusting screw should always be released, since this must be done before the cylinder valve is opened again. The acetylene and oxygen pressures should not be released simultaneously and care should be taken that the release of acetylene does not create a fire hazard. If acetylene is supplied through a hydraulic back-pressure valve, first simply close the service valve. After regulators are removed from cylinders, the dust plugs should be screwed in place on the cylinder connection nuts.

When regulators are to be out of service for several weeks or longer, it is good practice to turn the pressure adjusting screw "in" just enough to relieve the spring pressure on the valve seat. This aids in lengthening the life of the valve seat, especially when the seat is made of relatively soft material.

Before putting the regulator into service again, turn the pressure adjusting screw "out" until tension is released.

BACKFIRE AND FLASHBACK

Improper operation of the torch may cause the flame to go out with a loud snap or pop. This is called a **backfire.** Shut the torch valves, check the connections and operation, and then relight. A backfire may be caused by touching the tip against the work, by over-heating the tip, by operating the torch at other than recommended gas pressures, by a loose tip or head, or by dirt on the seat.

If the flame flashes back inside the torch, close the torch oxygen valve at once, then close the acetylene valve. A **flashback** occurs when the flame burns back inside the torch, usually with a shrill hissing or squealing. Closing the torch oxygen valve that controls the flame stops the flashback at once. Then the acetylene valve should be closed, the oxygen and acetylene regulators closed, and the torch allowed to cool before relighting. Also, blow oxygen through the torch tip for a few seconds to clear out any soot that may have accumulated in the passages.

Flashbacks may extend back into the hose or regulators. When flashbacks occur, they mean that something is radically wrong — either with the torch or with the way it is being operated. Any case should be investigated to determine the cause before relighting the torch. A clogged orifice or incorrect oxygen and acetylene pressures are often responsible. Avoid using gas pressures higher than those recommended by the manufacturer.

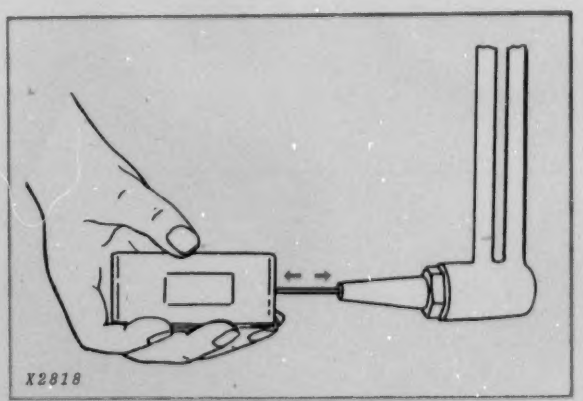

Fig. 21 — Using A Welding Tip Orifice Cleaner

CARE AND CLEANING OF TORCH TIPS

The welding tip is subjected to mechanical wear, flame erosion, and plugging.

Here are some hints for the care of torch tips:

1. Inspect threads on threaded tips periodically. (Never use pliers — use only box end wrenches.)

2 Never try to remove a hot tip from its torch tube. Allow it to cool first. Also, do not install a cold tip onto a hot torch tube.

3. Use a sized tip cleaner to unplug tip orifices (Fig. 21). When welding, molten metal droplets may be thrown into the tip orifices. Also, carbon soot may deposit in the tip. A good sign that the tip is clogged is difficulty in getting a neutral flame.

Fig. 22 — Welding In The Field With A Portable Oxy-Acetylene Outfit

4. Check tips for flame erosion periodically. Always use tips made for a particular torch.

5. On tips with gasket seals, tighten only hand tight. A wrench is not recommended.

6. Avoid dropping a tip as the seat which seals the joint may be damaged.

7. Try to avoid contacting the torch tip with the welding work, bench, or firebricks. This may damage the end of the tip and cause the flame to burn with a "fishtail."

OTHER TYPES OF GAS WELDING

We will briefly review these other types of gas welding:

- **Oxy-Mapp welding**
- **Oxy-hydrogen welding**
- **Air-acetylene welding**

These methods are less common than oxy-acetylene, especially for general maintenance work.

OXY-MAPP WELDING

Mapp gas is a Dow Chemical Company product developed as a fuel for welding, brazing, cutting, flame hardening, and metallizing operations. It has many of the physical properties of acetylene but lacks its shock sensitivity. Mapp gas is the result of rearranging the molecular structure of acetylene and propane.

Flame and Temperature Comparison of Fuel Gases

Fuel	*Maximum Flame Temperature In Oxygen*		*Maximum Burning Velocity In Oxygen*	
	(°F)	*(°C)*	*ft./sec*	*m/sec*
Acetylene	5589	3090	9.8	3
Mapp Gas	5301	2930	7.9	2.4
Propane	4579	2528	5.5	1.7

Acetylene is unstable under heat, but this produces a very high flame temperature which is one reason for its extensive use as a welding gas. Although propane itself has the desired stability its limiting factor for welding is its low flame temperature. The table above shows the flame temperatures and burning velocities of these gases. Notice that while acetylene produces a hotter flame it has a higher burning rate in oxygen, which often means greater gas consumption.

Since Mapp gas is not sensitive to shock it can be stored and shipped in lighter cylinders. Acetylene, to be kept safe, must be stored in cylinders filled with a porous filler and acetone. Where empty acetylene cylinders weigh around 220 pounds (100 kg), Mapp cylinders weigh only 50 pounds (23 kg). Normally a filled cylinder of acetylene weighs 240 pounds (109 kg), while a filled cylinder of Mapp gas weighs 120 pounds (54 kg).

Mapp gas has a very distinct odor so any leakage can readily be detected. For actual welding, the same equipment and operations can be used. However, a slightly larger tip is required because

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of the greater gas density and slower flame propagation rate. The only significant difference is in the flame appearance. A neutral flame will produce a long inner cone and needs fuel-to-oxygen ratio of 1 to 2.3.

The explosive limits of the vapor of Mapp gas in air and oxygen are much narrower than acetylene and about the same as propane and natural gas. It can be used at full pressure safely [up to 375 psi (2585 kPa)] for jobs that are dangerous with acetylene.

OXY-HYDROGEN WELDING

The oxy-hydrogen flame is produced by burning two volumes of hydrogen (H_2) with one volume of oxygen (O_2). The resulting combustion generates a low-temperature flame which is used primarily for welding thin sections of aluminum, aluminum alloys, and lead, and for brazing operations where lower temperatures are required.

The equipment for oxy-hydrogen welding is essentially the same as used in oxy-acetylene welding except that a special hydrogen pressure regulator is used.

One of the unusual characteristics of oxy-hydrogen is that the flame is practically non-luminous. Consequently, it is often difficult to adjust for a neutral flame. To avoid welding with what might be an oxidizing flame, the practice is to adjust the regulator so it provides a greater flow of hydrogen. The excess hydrogen is harmless since the reducing atmosphere does not leave carbon deposits.

AIR-ACETYLENE WELDING

The air-acetylene flame is generated by burning a mixture of acetylene with air. The torch operates on the same principle as the Bunsen burner. As the acetylene flows to the torch under pressure, it draws in the right amount of air for proper combustion.

The temperature of the air-acetylene flame is even lower than that of the oxy-hydrogen and so it has restricted uses for welding. Generally, the air-acetylene flame is used for soldering and brazing very light metal sections. It has wider applications in the plumbing industry where it is used for soldering and brazing of copper tubing.

TEST YOURSELF

QUESTIONS

1. Why is oxy-acetylene welding used more for small shop jobs than for large production welding?

2. In a welding flame, what is the function of the inner and outer combustion stages?

3. Why are gas cylinders equipped with safety devices?

4. Match each item on the left below with the correct description on the right.

a. Carburizing flame	*1. Sharp inner cone, no feather. Used for most welding.*
b. Oxidizing flame	*2. Flame has pale blue color, no sharp inner cone.*
c. Neutral flame	*3. Long "feather" around inner cone of flame.*

5. At what angle to the completed weld should the torch be held during welding?

6. How does the forehand differ from the backhand welding technique?

7. Which welding technique — forehand or backhand — is generally recommended for welding metals heavier than ⅛ inch (3.2 mm)?

8. When stopping work, why should the cylinder valve be closed and the torch valve opened as a preliminary step?

(Answers on page 121.)

ARC WELDING / PART 2

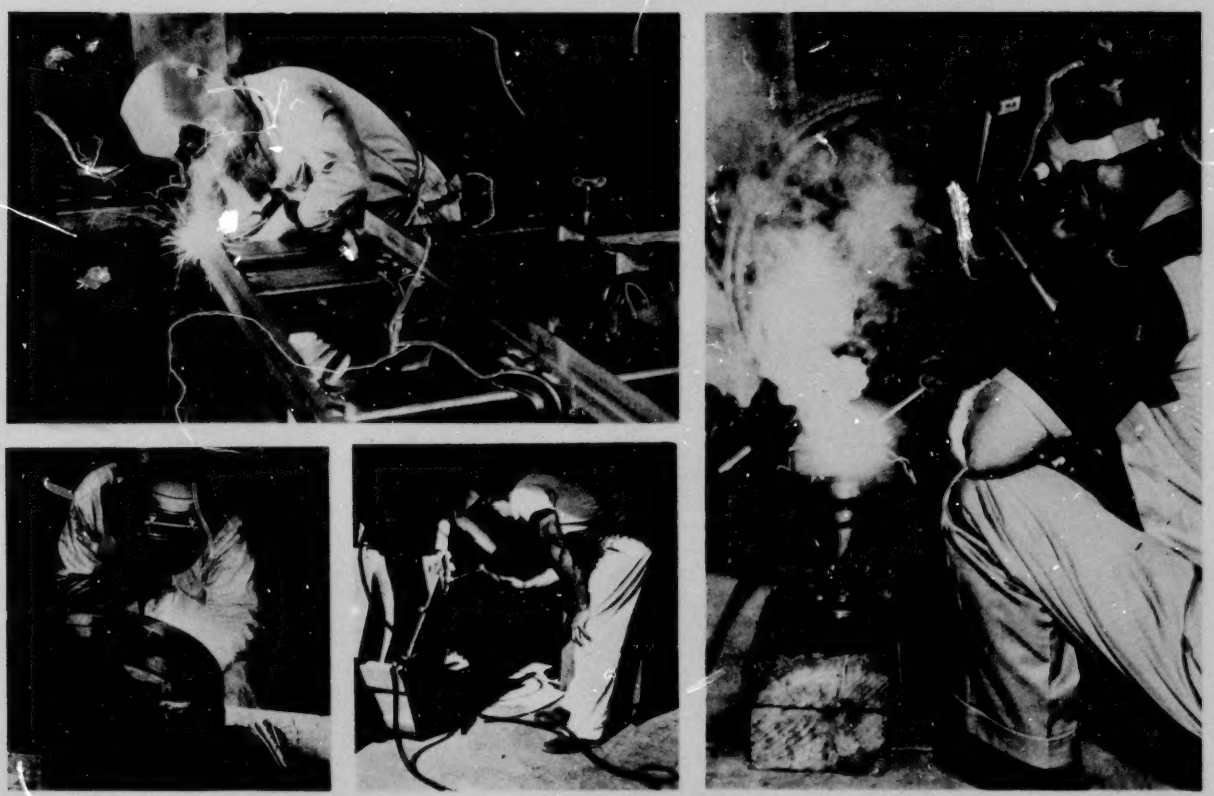

Fig. 23 — Arc Welding

INTRODUCTION

In arc welding, two metals are joined by generating an electric arc between a covered metal electrode and the base metals.

The heat produced by the arc melts the metal which mixes with the molten deposits of the coated electrode. The arc energy is provided by a power supply unit that furnishes direct or alternating current. The electrodes carry the current to form the arc, produce a gas which shields the arc from the atmosphere, and add metal to control the weld shape (Fig. 24).

When an arc is struck using a coated electrode, the intense heat melts the tip of the electrode. The tiny drops of metal from the electrode enter the arc stream and are deposited on the base metal. As the molten metal is deposited, a slag forms over the weld which insulates it against the contaminants of the air while it cools.

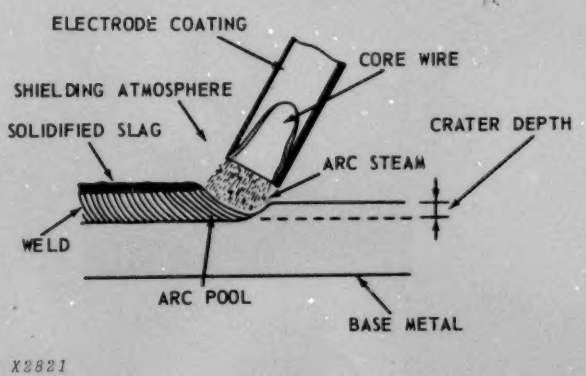

Fig. 24 — Basic Action Of Arc Welding

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EQUIPMENT

The following equipment is needed for electric arc welding:

- **Power supply**
- **Electrode holder**
- **Ground clamp**
- **Protective shield**
- **Welder's clothing**

Let's look at each piece of equipment in detail.

POWER SUPPLY

For effective arc welding, a *constant current* is required. The welding machine must have a drooping volt-ampere curve in which *a relatively constant supply of current is produced with only a limited change in voltage load.*

In other electrical appliances the demand for current usually remains fairly constant, but in arc welding the power fluctuates a great deal. Thus, when the arc is struck with the electrode a short circuit results which immediately induces a sudden surge of electrical current unless the machine is designed to prevent this. Similarly, when molten globules of weld metal are carried across the arc stream, they also create a short circuit. A constant-current power supply is designed to reduce these sudden surges of short circuits and so prevent excessive spattering during welding.

In arc welding the open-circuit voltage (voltage when the machine is running and no welding is being done) is much higher than the arc voltage (voltage after the arc is struck). The open-circuit voltage may vary from 50 to 100 and the arc voltage 18 to 36. During the welding process the arc voltage will also change with differences in arc length.

Since it is difficult for even a skilled operator to maintain a uniform arc length at all times, a machine with a steep volt-ampere curve will produce a more stable arc, because there will be almost no change in welding current even with changes in arc voltage. A volt-ampere curve shows the output voltage available at any given output current within the limits of the minimum and maximum current control setting on each range.

For example, the curve in Fig. 25 indicates that a high open circuit voltage is available at 0 which helps in starting the arc. As welding proceeds, the voltage drops to the arc voltage at A and at this point fluctuation in the arc length will hardly affect the current. If the electrode is short circuited on the work, the current will not become excessive, as indicated at B.

The current used directly affects the melting rate. As the rate of current is increased, the current density at the electrode tip also is increased. The amount of current required for any welding operation is governed by the thickness of the work metal. This current is controlled by a wheel or lever arrangement. One control sets the machine for an approximate current setting and another control provides a more accurate current adjustment.

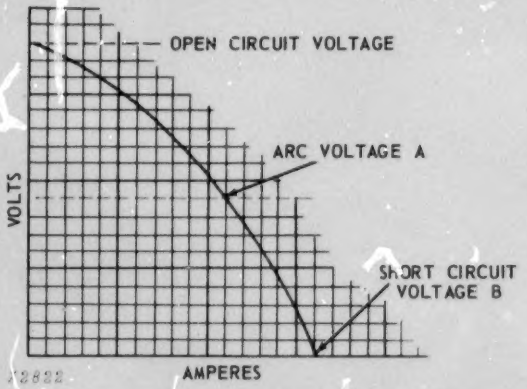

Fig. 25 — Volt-Amp Curve Showing Relationship Between Output Voltage and Output Current

Three basic welding machines are used in arc welding:

- **Generators — usually direct current**
- **Transformers — for alternating current**
- **Rectifiers — for choice of currents**

Welding machines are sized according to their output rating, which may range from 150 to 600 amperes.

The output rating is based on a **60** *percent duty cycle.* This means that a power supply can deliver its rated load output for six minutes out of every ten minutes. In manual welding, a power source is not required to provide current continuously, as on other electrical machines. For some electrical devices, once the power is turned on it must deliver its rated output until it is shut off. With a welding power supply, the machine is often

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idle part of the time while the operator changes electrodes, adjusts the work, or shifts welding positions. Thus the standard method of rating a machine is to show the percentage of time that it must actually deliver power. (For this reason, fully automatic power supply units are usually rated at 100 percent duty cycle.)

The size of welding machine to be used depends on the kind and amount of welding to be done. The following is a general guide for selecting a welding machine.

150-200 ampere — For light-to medium-duty welding. Excellent for all fabrication and rugged enough for continuous operation on light or medium production work.

250-300 ampere — For average welding requirements. Used in plants for production, maintenance, repair, tool-room work, and all general shop welding.

400-600 ampere — For large and heavy-duty welding. Especially good for structural work, fabricating heavy machine parts, pipe and tank welding.

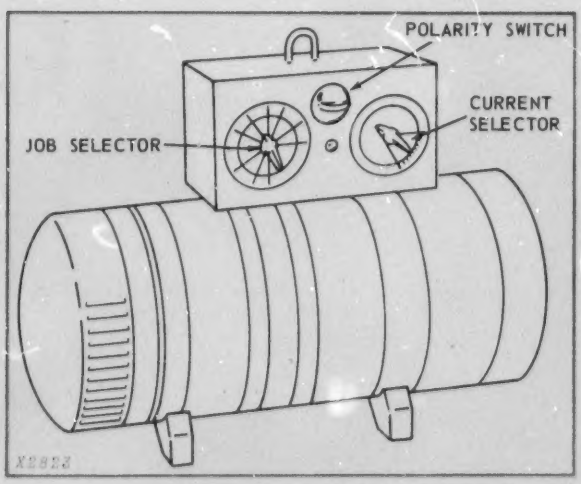

Fig. 26 — DC Generator As Power Supply For Arc Welding

DC Generator

The *direct-current* power supply consists of a generator driven by an electric motor or a gasoline engine (Fig. 26).

One of the characteristics of a direct-current welding generator is that the welding can be done with straight or reverse polarity. *Polarity* indicates the direction of current flow in a circuit. In straight polarity, the electrode is negative and the workpiece positive and the electrons flow from the electrode to the workpiece. See Fig. 27. In reverse polarity, the electrode is positive and the workpiece negative and the electrons flow from the workpiece to the electrode.

Polarity is changed by switching cables, although on modern machines changing polarity is done by simply turning a switch.

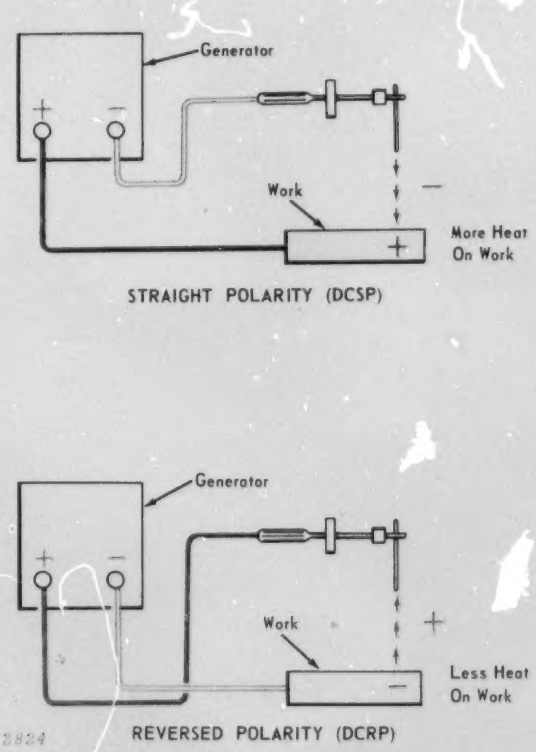

Fig. 27 — With D.C. Power Supply, Welding Can Be Done With Straight Or Reverse Polarity

Polarity affects the liberated heat since it is possible to control the amount of heat going into the base metal. By changing polarity, the greatest heat can be concentrated where it is most needed.

Usually it is preferable to have more heat at the workpiece because the area of the work is greater and more heat is required to melt the metal than

the electrode. Thus, if large heavy deposits are to be made, the work should be hotter than the electrode. For this purpose, *straight polarity* is more effective.

On the other hand, in overhead welding it is necessary to quickly freeze the filler metal to help hold the molten metal in position against the force of gravity. By using *reverse polarity,* less heat is generated at the workpiece, giving the filler metal greater holding power for out-of-position welding.

In other situations, it may be better to keep the workpiece as cool as possible, as in repairing a cast-iron casting. With reverse polarity, less heat is produced in the base metal and more heat at the electrode. The result is that the deposits can be applied rapidly while the base metal is prevented from overheating.

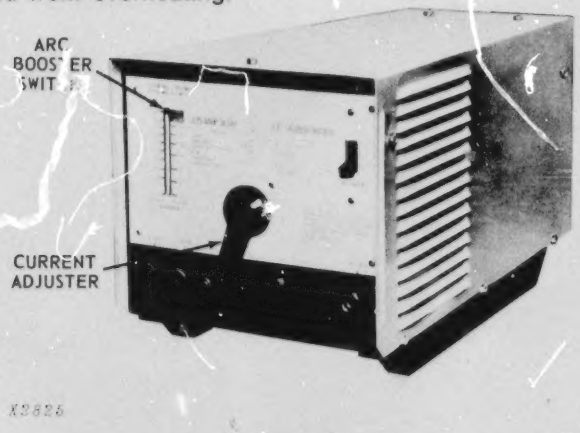

Fig. 28 — A.C. Transformer Welding Unit

Transformer

The transformer welding machine produces *alternating current.* Power is taken directly from a power supply line and transformed into a voltage required for welding. See Fig. 28.

The simplest AC transformer has a primary and a secondary coil with an adjustment to regulate the current output. The primary coil receives the alternating current from the source of supply and creates a magnetic field which constantly changes in direction and strength. The secondary coil has no electrical connection to the power source but is affected by the changing lines of force in the magnetic field; through induction it delivers a transformed current at a higher value to the welding arc.

Some AC transformers are equipped with an arc booster switch which supplies a burst of current for easy arc starting when the electrode comes in contact with the work. After the arc is struck, the current automatically returns to the amount set for the job. The arc booster switch has several settings to permit quick arc starting for welding either thin sheets or heavy plates.

One advantage of the AC welding machine is freedom from *arc blow* which often occurs when welding with DC machines. Arc blow causes the arc to wander while welding in corners on heavy metal or when using large coated electrodes. Direct current flowing through the electrode, workpiece, and ground clamp generates a magnetic field around each of these units which may cause the arc to deviate from its intended path. The arc usually is deflected either forward or backward along the line of travel and may cause excessive spatter and incomplete fusion. It also tends to pull atmospheric gases into the arc, resulting in porosity. The bending of the arc is due to the effects of an unbalanced magnetic field. Thus when a great concentration of magnetic flux develops on one side of the arc it tends to blow away from the source of greatest concentration.

Arc blow can often be corrected by changing the position of the ground clamp, welding away from the ground clamp, or changing the position of the weldpiece on the workbench.

Rectifiers

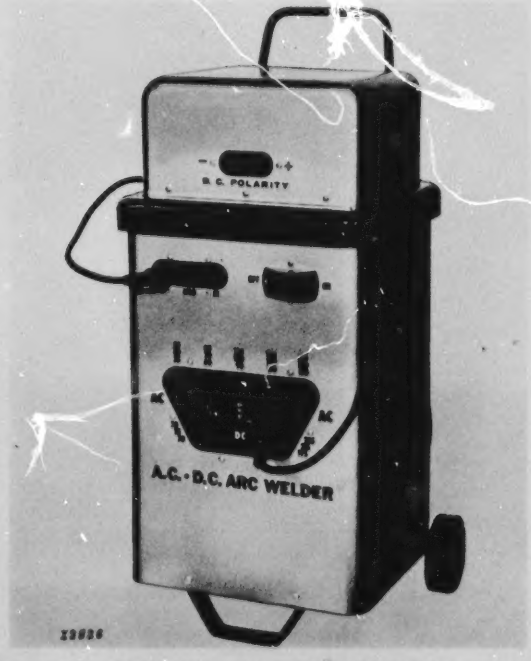

Fig. 29 — Combination A.C.-D.C. Rectifier Welding Unit

Rectifiers are transformers which contain an electrical device changing alternating current into direct current.

The rectifiers for arc welding are usually of the constant-current type where the welding current remains reasonably constant for small variations in arc length.

Rectifiers are made to provide DC current only, or both DC and AC welding current. See Fig. 29. By means of a switch, the output terminals can be changed to the transformer or to the rectifier, producing either AC current or DC straight or DC reverse polarity current.

At present, the two rectifier materials used for welding machines are selenium and silicon. Both are excellent, although silicon will often permit operation at higher current densities.

ELECTRODE HOLDER

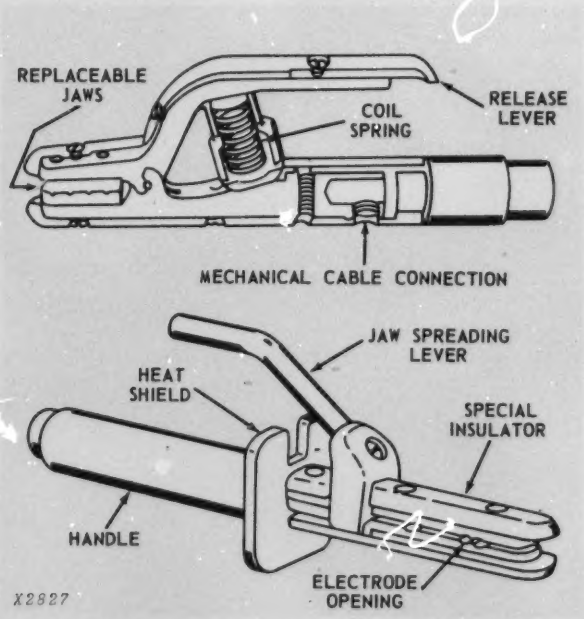

Fig. 30 — Two Common Types Of Insulated Electrode Holders

The electrode holder (Fig. 30) is used to hold the electrode and guide it over the seam to be welded. A good holder should be light to reduce excessive fatigue while welding, receive and eject electrodes easily, and be properly insulated. Some holders are fully insulated, while in others only the handle is insulated.

When using a holder with uninsulated jaws, never lay it on the bench plate while the machine is running because it will cause a flash.

Always connect holders firmly to the cable. A loose connection where the cable joins the holder may overheat the holder.

The use of large enough cable is also necessary for proper welding. A 30-ft. (900 mm) lead cable of a given size may be satisfactory to carry the required current, but if another 30 ft. (900 mm) of cable is added, the combined resistance of the two leads reduces the current output of the machine. If the machine is then readjusted for a higher output, the additional load may cause the power supply to overheat and also increase its power consumption.

The primary cable which connects the welding machine to the source of electricity is also significant. The length of this cable has been determined by the manufacturer of the power supply unit and represents a length that permits the machine to operate efficiently without an appreciable drop in voltage. If a longer cable is used, more voltage will be required for the work to be done, and if no more voltage is available, the resulting voltage drop will seriously affect the welding.

Fig. 31 — Ground Clamps

GROUND CLAMP

The ground clamp (Fig. 31) is vital to an electrical welding outfit. Without proper grounding, the full potential of the circuit will fail to provide the required heat for welding.

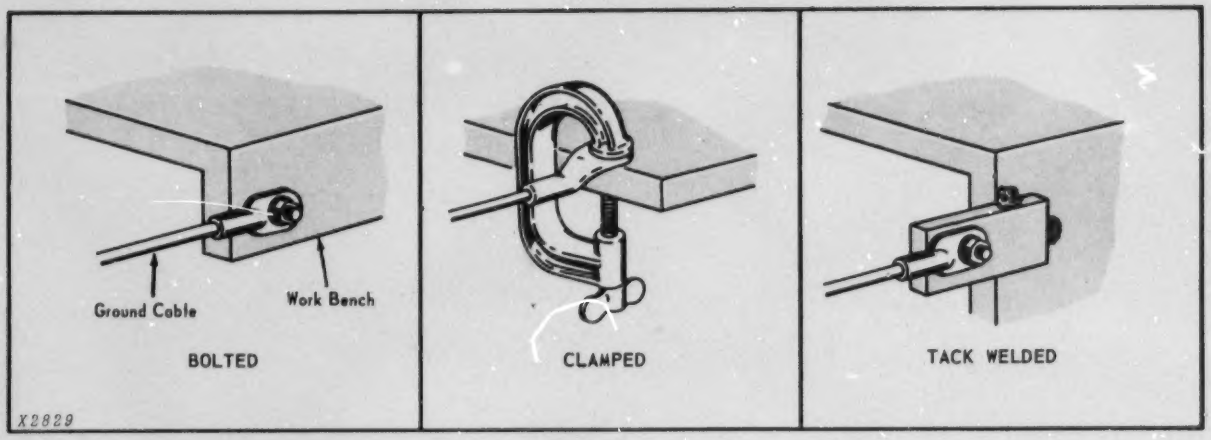

Fig. 32 — Three Types Of Preferred Ground Connections

Types Of Ground Connections

A good ground connection can be made in several ways. The ground cable may be fastened to the work bench by a C-clamp, a special ground clamp, or by bolting or welding a lug on the end of the cable to the bench. See Fig. 32.

NOTE: The fused surface area of the tack weld must equal the cross-sectional area of the ground cable for efficient operation.

PROTECTIVE SHIELD

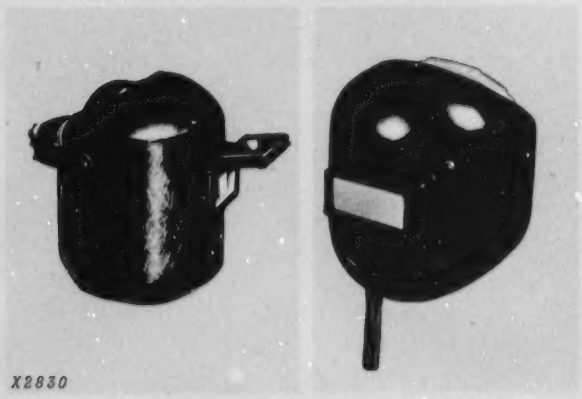

Fig. 33 — Always Use A Helmet Or Shield When Arc Welding

A suitable helmet or handshield is required for all arc welding (Fig. 33). An electric arc produces a brilliant light and also gives off invisible ultraviolet and infrared rays which can burn the eyes and skin. **Never look at the arc with the naked eye within a distance of 50 feet (16 m).**

Both the helmet and handshield are equipped with special colored lenses that reduce the brilliancy of the light and screen out the infrared and ultraviolet rays.

Lenses come in different shades for various welding. In general, the recommended practice is as follows:

Shade 5 for light spot welding
Shade 6 and 7 for welding up to 30 amperes
Shade 8 for welding 30 to 75 amperes
Shade 10 for welding 75 to 200 amperes
Shade 12 for welding 200 to 400 amperes
Shade 14 for welding over 400 amperes

Fig. 34 — Welder's Protective Clothing

WELDER'S CLOTHING

The welder in Fig. 34 is fully clothed for welding safety.

Gloves should be heavy-duty with long cuffs. Regulation leather welding gloves are available. Use asbestos gloves when working in intense heat. However, use clamps — not gloves — to pick up hot metal.

Leather sleeves give extra protection from sparks and intense heat.

Leather or asbestos aprons are recommended for heavy welding or cutting.
Wear heavy shoes and never roll the pant legs or molten metal may fall into them. If possible, remove or cover pockets in the front of trousers or shirts.

Cover the head with a protective cap and always keep the protective shield in place.

HOW TO ARC WELD

In this section we will cover preparation for welding, various weld positions, type of joints, starting the arc, setting the current, and techniques for welding.

PREPARING TO WELD

Before starting to weld, observe all rules for safety and cleaning the metal to be welded.

Safety Rules

Observe all *safety* precautions. Here are the basic rules:

1. Be sure the welding area has a cement or masonry floor.

2. Keep all combustible materials at a safe distance.

3. Do not use gloves or other clothing which contain oil or grease.

4. Be sure all power wiring is correctly installed and maintained. Don't overload the welding cables.

5. Always be sure your machine is properly grounded. Never work in a damp area.

6. Shut off the welding machine before making repairs or adjustments to avoid shocks.

(Continued on page 23.)

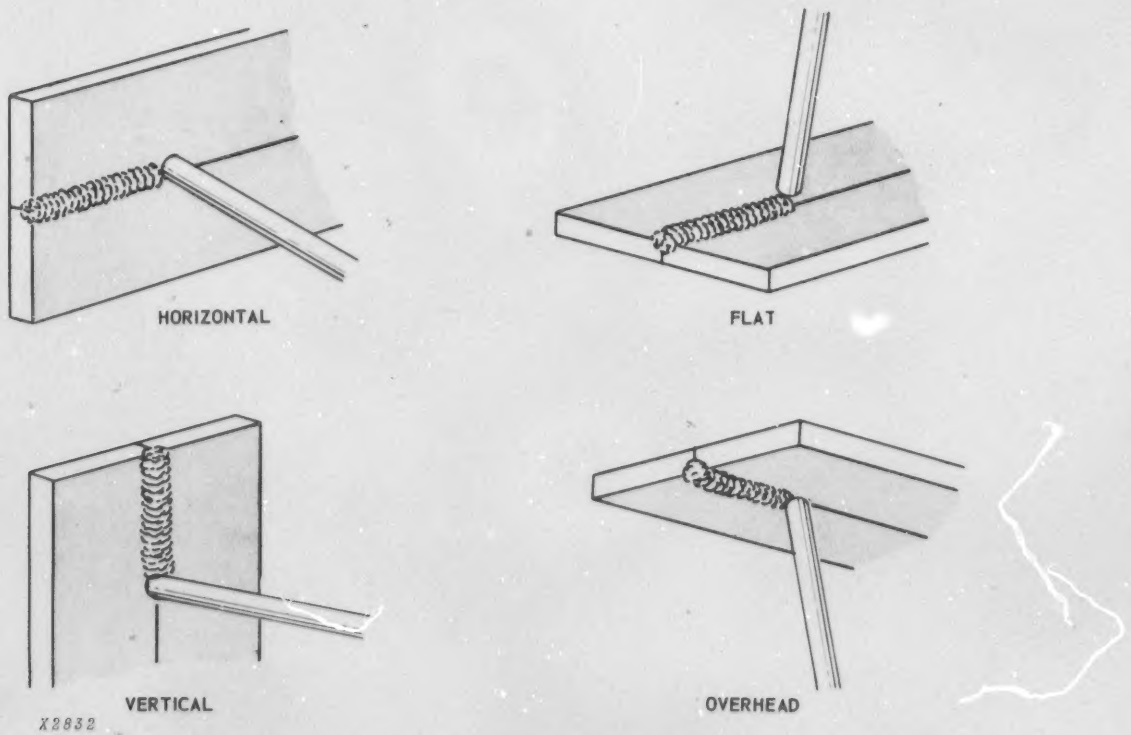

Fig. 35 — Four Basic Welding Positions

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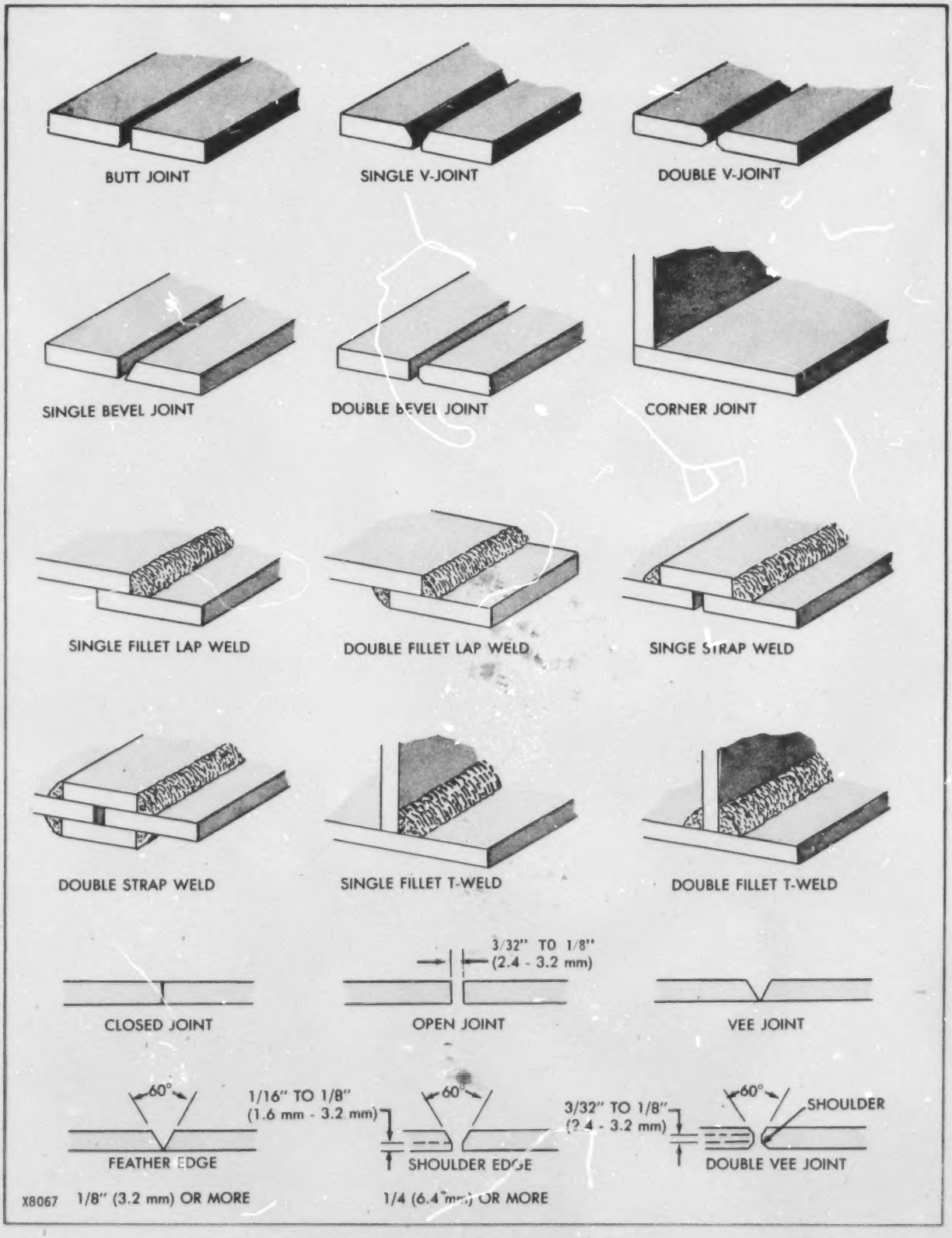

Fig. 36 — Types Of Joints And Welds Used In Welding

7. Follow the manufacturer's rules on operating the switches, and making other adjustments.

8. Protect others with a screen and yourself with a protective shield. Flying sparks are a danger to your eyes. Arc rays can also cause painful burns.

9. Keep firefighting equipment handy at all times.

NOTE: For complete safety rules, see "Part 8 — "Welding Safety."

Cleaning Metal To Be Welded

Clean all rust, scale, paint, or dirt from metal joints to be welded. Also be sure the metals are free of oil.

WELDING POSITIONS

Arc welding can be done in any of the four basic positions shown in Fig. 35 on page 21:

- **Horizontal**
- **Flat**
- **Vertical**
- **Overhead**

The *flat* position is generally easier and faster, plus giving better penetration.

TYPES OF JOINTS

The basic types of joints used in joining metal products are illustrated in Fig. 36. Joint design is discussed more fully in Part 6, "Design of Welds." Notice that butt joints are either closed or opened.

A closed butt joint has the edges of the two plates in direct contact with each other. This joint is suitable for welding steel plates that do not exceed ⅛ to 3/16 inch (3.2 to 4.8 mm) in thickness. Heavier metal can be welded but only if the machine has sufficient amperage capacity and if heavier electrodes are used.

The **open butt joint** has the edges slightly apart to provide for better penetration. Very often a backup bar of steel, copper, or brick is placed under an open joint to prevent the bottom edges from burning through.

When the thickness of metal exceeds ⅛ or 3/16 inch (3.2 or 4.8 mm), the edges have to be *bevelled* for better penetration.

Bevelling may be confined to one plate or the edges of both plates are beveled, depending on the thickness of the metal. Angle of bevel is usually 60° between the two plates as shown.

STARTING THE ARC

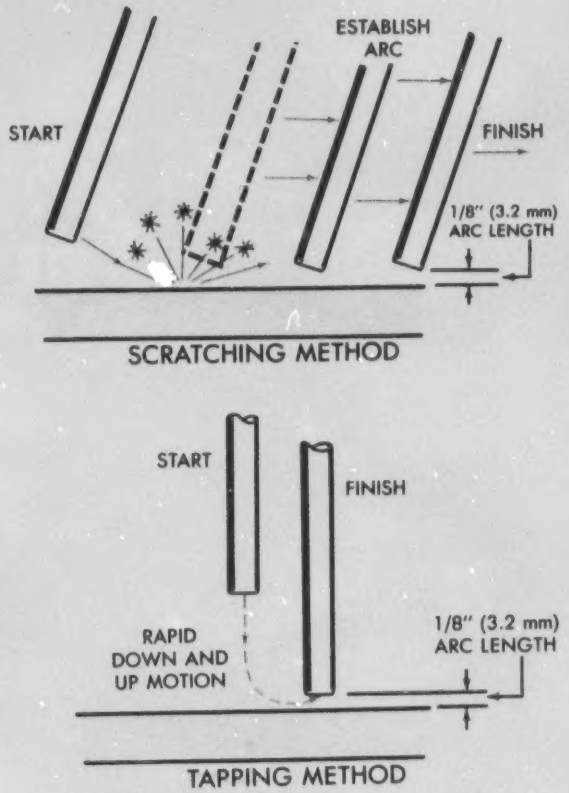

Fig. 37 — Starting The Arc — Two Methods

To start the arc, tap or scratch the electrode on the work (Fig. 37).

As soon as the arc is started, immediately raise the electrode a distance equal to the diameter of the electrode. Failure to raise the electrode causes it to stick to the metal. If it is allowed to remain in this position with the current flowing, the electrode will become red hot.

When an electrode does stick, it can be broken loose by quickly twisting or bending it. If it does not dislodge, release the electrode from the holder.

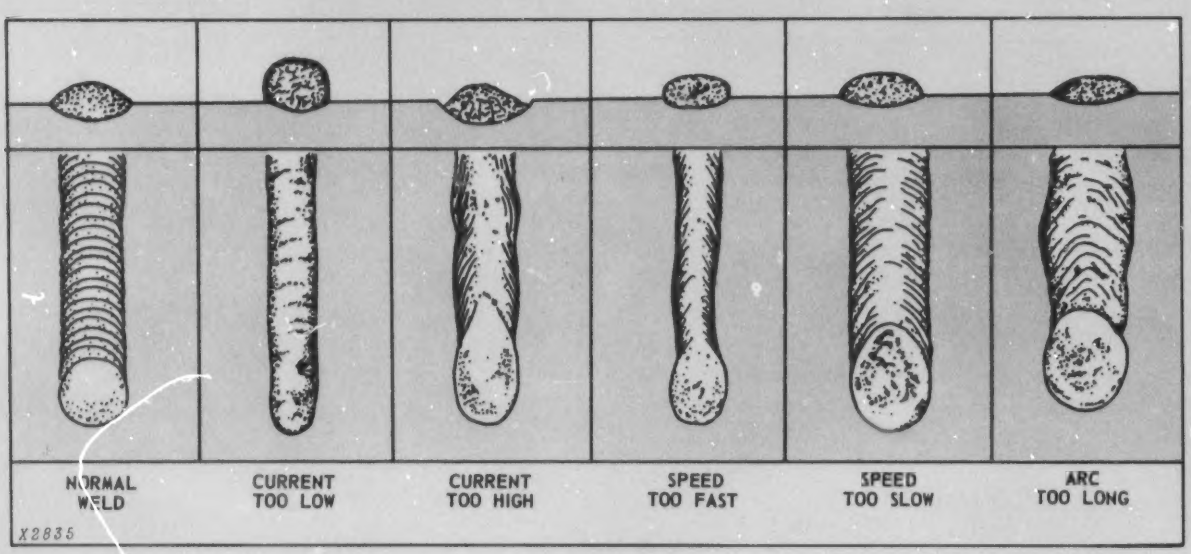

Fig. 38 — Good And Bad Welds

SETTING THE CURRENT

The amount of current to be used depends upon:

1. *The thickness of the metal to be welded*
2. *The actual position of welding, and*
3. *The diameter of the electrode.*

As a rule, higher currents and larger diameter electrodes can be used for welding in flat positions than in vertical or overhead welding.

Electrode diameter is governed by the thickness of the plate and welding position. For most flat position welding, the electrodes should be $^{5}/_{16}$ or $^{3}/_{8}$ inch (8 or 9.5 mm) maximum, while $^{3}/_{16}$ inch (4.8 mm) should be the maximum for vertical and overhead welding.

Manufacturers of electrodes generally specify a range of current values for various diameter electrodes. However, since the recommended current setting is only approximate, final current adjustment is made during welding.

For example, if the current range for an electrode is 90-100 amperes, the usual practice is to set the control midway between the two limits. After starting to weld, make a final adjustment by either increasing or decreasing the current.

Whenever the *current is too high,* the electrode will melt too fast and the molten puddle will be too large and irregular.

Where the *current is too low,* there will not be enough heat to melt the base metal and the molten pool will be too small. The result is not only poor fusion but the deposit will pile up and be irregular in shape. See Fig. 38.

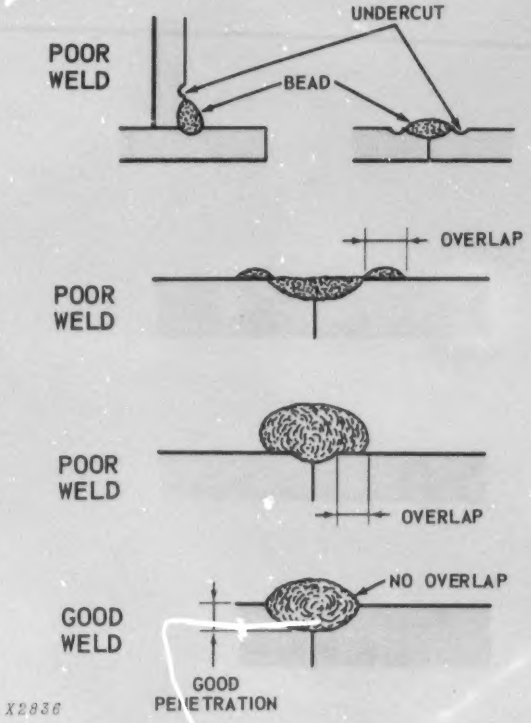

Fig. 39 — Avoid Undercuts And Overlays In Welding

Too high a current may also produce *undercutting,* (Fig. 39) which leaves a groove in the base metal along both toes of the weld deposit.

A current that is set too low will cause *cold laps to* form where the molten metal from the electrode falls on the work without sufficiently fusing or penetrating the base metal. Both undercutting and cold lap result in weak welds. See Fig. 39.

LENGTH OF ARC

If the *arc is too long* the metal melts off the electrode in large globules which wobble from side to side as the arc wavers. This produces a wide, spattered, and irregular deposit without sufficient fusion between the original metal and the deposited metal (see Fig. 38).

An *arc that is too short* fails to generate sufficient heat to melt the base metal properly. Also, the electrode will stick frequently and produce uneven deposits with irregular ripples.

The length of the arc depends on the type of electrode used and the kind of welding done. Thus, for small diameter electrodes, a shorter arc is necessary than for larger electrodes. Generally, *the length of the arc should be approximately equal to the diameter of the electrode.*

A shorter arc is usually better for vertical and overhead welding because better control of the molten puddle is achieved.

The use of a short arc also prevents impurities from the atmosphere entering the weld. A long arc allows the atmosphere to flow into the arc stream, permitting nitrides and oxides to form. Moreover, when the arc is too long, heat from the arc stream is dissipated too rapidly, causing considerable metal spatter.

When the electrode, current, and polarity are correct, **a good short arc will produce a sharp, crackling sound.** *A long arc can be recognized by a steady hiss very much like escaping steam. See Fig. 40.*

TRAVEL SPEED

Travel speed is the rate the electrode travels along the weld seam. The maximum speed of welding is influenced by the skill of the operator, the position of the weld, the type of electrode, and the required joint penetration.

Normally, if the *speed is too fast,* the molten pool will solidify or freeze quickly trapping impurities in the weld deposit. The weld bead usually is narrow with pointed ripples (see Fig. 38).

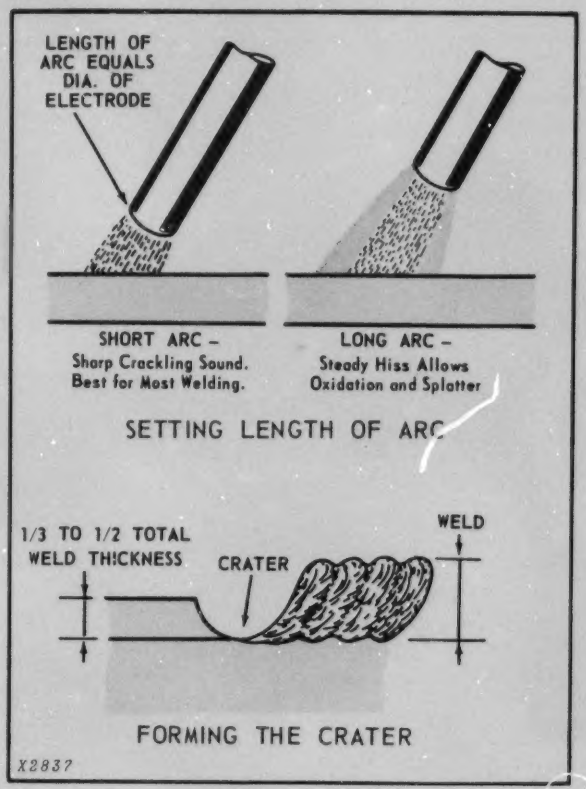
LENGTH OF ARC EQUALS DIA. OF ELECTRODE
SHORT ARC – Sharp Crackling Sound. Best for Most Welding.
LONG ARC – Steady Hiss Allows Oxidation and Splatter
SETTING LENGTH OF ARC
1/3 TO 1/2 TOTAL WELD THICKNESS
CRATER
WELD
FORMING THE CRATER
X2837

Fig. 40 — Setting Length Of Arc And Forming Proper Crater

On the other hand, if the *travel is too slow,* the metal piles up excessively and the weld bead is high and wide (see Fig. 38).

In most cases, the limiting speed is the highest speed that produces a satisfactory surface appearance. (See "Normal Weld" in Fig. 38.)

FORMING THE CRATER

As the arc comes in contact with the base metal, a pool or pocket is formed which is called a crater. The size and depth of a crater indicates the amount of penetration. In general, the depth of **penetration** *should be from* **one-third to one-half** *the total thickness of the weld bead depending upon the size of the electrode. See Fig. 40.*

For a sound weld, the metal deposited from the electrode must fuse completely with the base metal. Fusion will result only when the base metal has been heated to a liquid state and the molten metal from the electrode readily flows into it. Thus if the arc is too short there will be insufficient

spread of heat, or if the arc is too long the heat is not centralized enough to form the desired crater. An improperly filled crater may cause a weld to fail when a load is applied to the welded structure.

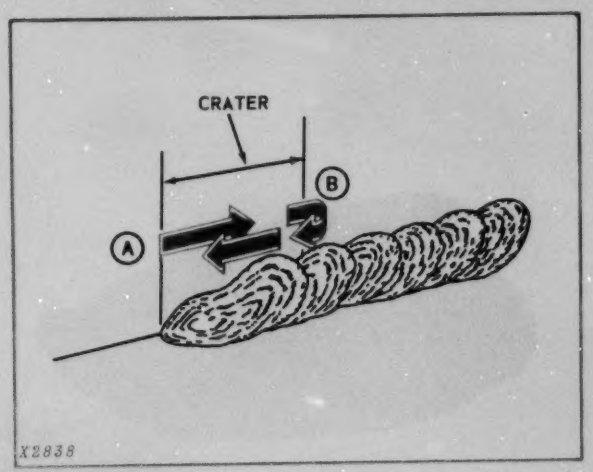

Fig. 41 — How To Properly Fill A Crater

When starting an electrode, there is always a tendency for a large globule of metal to fall on the surface of the plate with little or no penetration. This is especially true when beginning a new electrode at the crater left from a previously deposited weld. To ensure that the crater is filled, the arc should be struck approximately ½ inch (12.7 mm) in front of the crater as in A, Fig. 41. The arc should then be brought through the crater to point B beyond the crater and then the weld carried back through the crater.

When the electrode reaches the end of a seam, make sure that the crater is filled. This means breaking the arc at the right moment.

Two procedures are used to break the arc for a full crater:

1. Shorten the arc and move the electrode quickly sideways out of the crater.

2. Hold the electrode stationary just long enough to fill the crater and then gradually withdraw from it.

Occasionally, the crater may become too hot and the molten metal will run. When this happens, lift the electrode and shift it quickly to the side or ahead of the crater. This movement reduces the heat, allows the crater to solidify momentarily, and stops the deposit of metal from the electrode.

ELECTRODE POSITIONS

The angular position of the electrode has a direct influence in the quality of the weld. Often the position of the electrode determines the ease with which filler metal is deposited, prevents undercutting and slag, and keeps the weld contour uniform.

The two prime factors in electrode position are lead angle and work angle.

Lead angle is the angle between the joint and the electrode when viewed in a longitudinal plane (Fig. 42).

Work angle is the angle between the electrode and the work when viewed from an end plane.
Some of the basic electrode positions for flat, horizontal, vertical, and overhead welding are illustrated in Fig. 43.

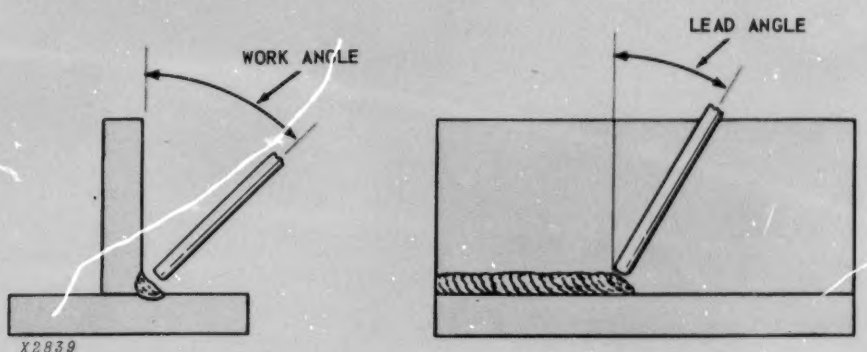

Fig. 42 — Hold The Electrode At The Proper Work And Lead Angles

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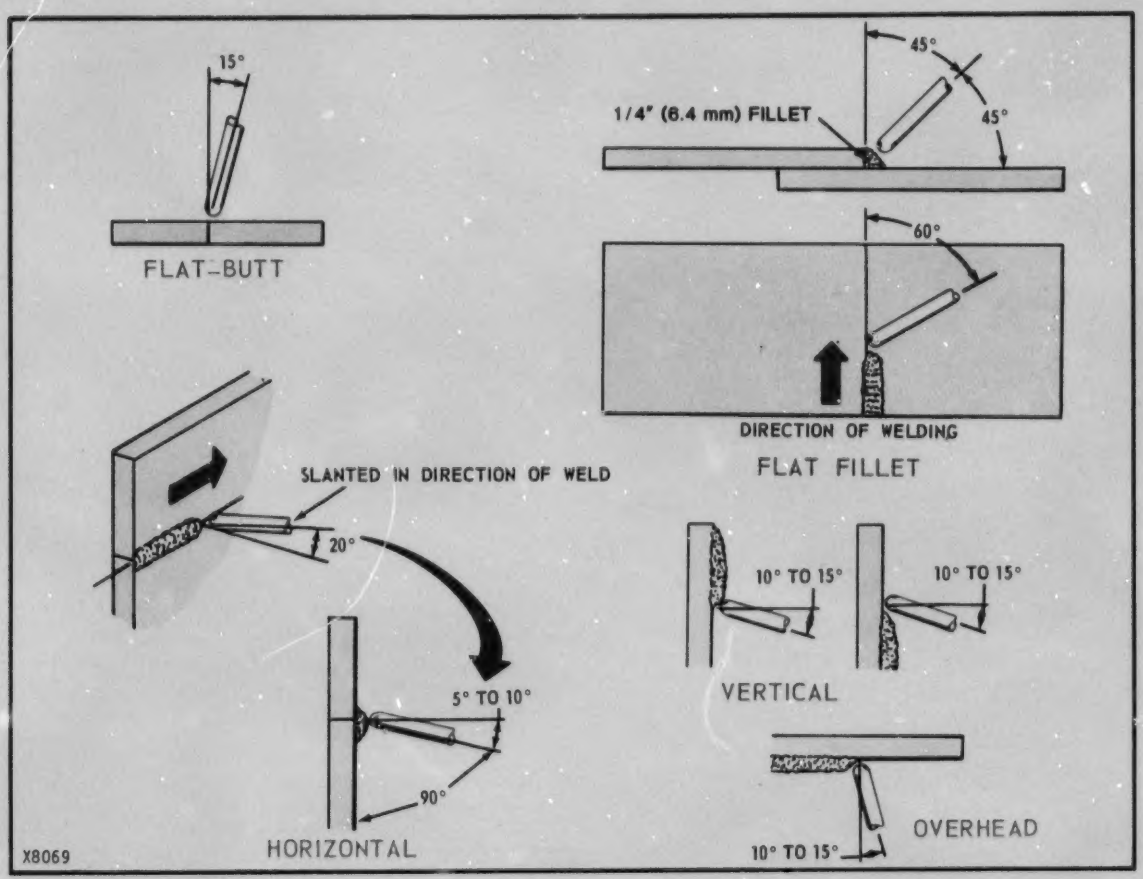

Fig. 43 — Electrode Positions For Flat, Horizontal, Vertical, And Overhead Welding

SINGLE AND MULTIPLE PASS WELDS

A single pass weld involves depositing one layer of weld metal. In welding light materials, a single pass is usually sufficient.

On heavier plates and where added strength is required, two or more layers are required with each weld pass lapping over the other (Fig. 44).

Whenever a multiple pass is used, the slag on each weld bead must be removed completely before the next layer is deposited.

WEAVING THE ELECTRODE

Weaving is a technique used to increase the width and volume of the weld deposit. Enlarging the size of the weld deposit is often necessary on deep grooves or fillet welds where a number of passes must be made. Fig. 45 illustrates several weaving patterns. The patterns used depend to a large extent on the position of the weld.

TYPES OF ELECTRODES

The type of electrode selected for arc welding depends upon:

1. **Quality of weld required.**
2. **Weld position.**
3. **Joint design.**
4. **Welding speed.**
5. **Composition of base metal.**

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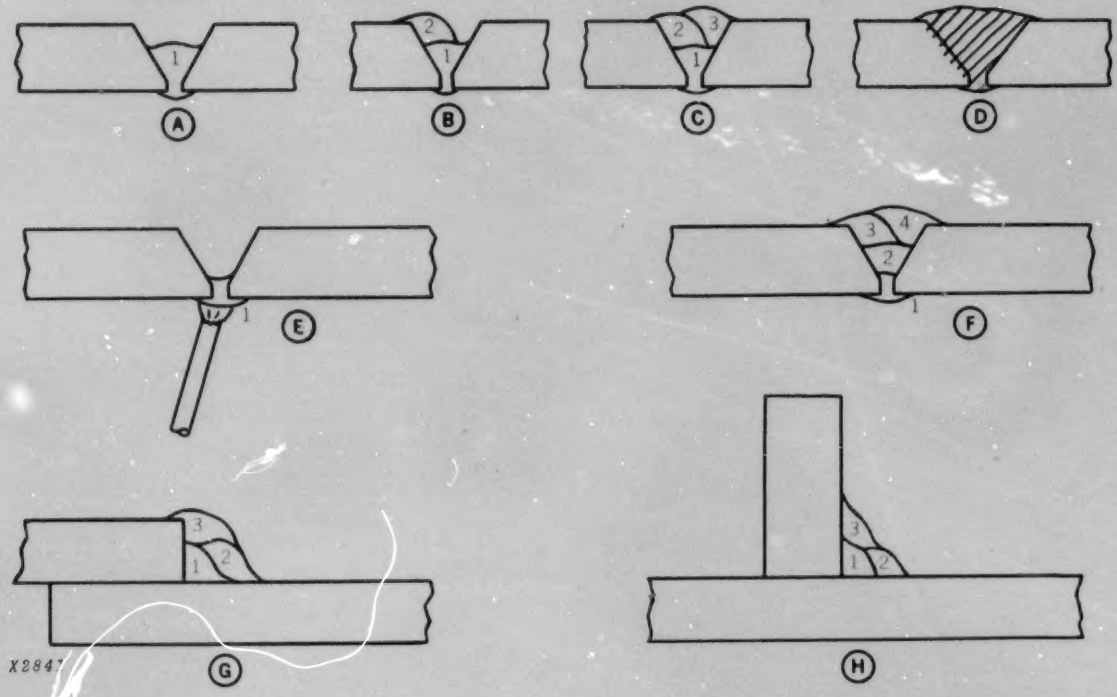

A. First or root pass in a butt joint.

B. Second pass.

C. Third pass.

D. Finished weld.

E and F. Butt joint where root pass is welded from penetration side of joint.

G. Lap joint welded in three passes.

H. T-joint welded in three passes.

Fig. 44 — Arc Welded Joints Which Were Welded In Multiple Passes

In general, all electrodes are classified into five main groups: *mild steel, high carbon steel, special alloy steel, cast iron* and *nonferrous*. The greatest range of arc welding is done with electrodes in the mild steel group

Electrodes are manufactured to weld different metals and they are also designed for DC straight and reverse polarity or AC welding. A few electrodes work equally well on either DC or AC. Some electrodes are best suited for flat position welding, others are intended primarily for vertical and overhead welding, and some are used in any position.

The shielded electrode has a heavy coating of several chemicals such as cellulose, titanimum dioxide, ferro-manganese, cilica flour, calcium carbonate, and others. These ingredients are bound together with sodium silicate.

Each of the substances in the coating is intended to serve a particular function in the welding process. In general, their main purposes are to induce easier arc starting, stabilize the arc, improve weld appearance and penetration, reduce spatter, and protect the molten metal from oxidation or, contamination by the surrounding atmosphere.

Molten metal as it is deposited in the welding process is attracted to oxygen and nitrogen. Since the arc stream takes place in an atmosphere consisting largely of these two elements, oxidation occurs while the metal passes from the electrode to the work. When this happens, the strength and ductility of the weld are reduced as well as its resistance to corrosion. *The coating on the electrode prevents oxidation from taking place.* As the electrode melts, the heavy coating releases an inert gas around the molten metal which excludes the atmosphere from the weld (Fig. 46).

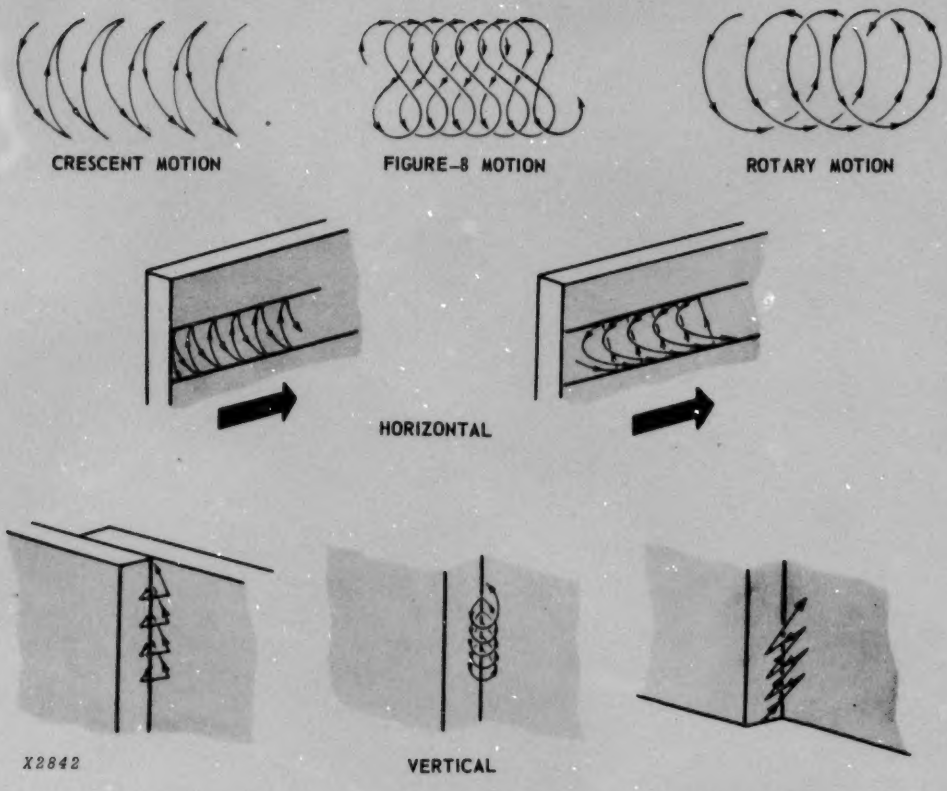

Fig. 45 — Weaving Patterns For Arc Welding (To Increase Width And Volume Of Weld Deposit)

The burning residue of the coating forms a slag over the deposited metal which slows down the rate of cooling and produces a more ductile weld.

Some coatings include powdered iron that is converted to steel by the intense heat of the arc and flows into the weld deposit.

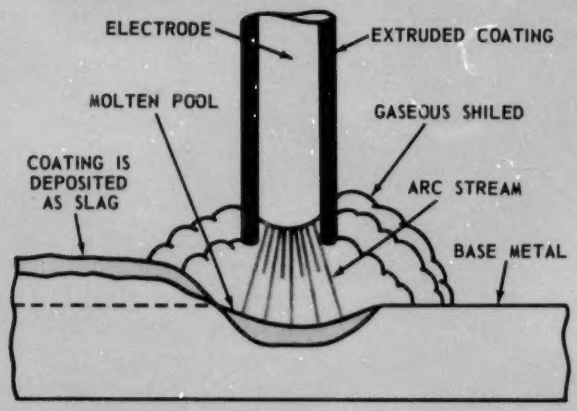

Fig. 46 — Electrode Covering Forms Gaseous Shield Which Protects Weld Metal From Atmosphere

IDENTIFYING ELECTRODES

Electrodes are often referred to by a manufacturer's trade name. To ensure some degree of uniformity in manufacturing electrodes, the American Welding Society (AWS) and the American Society for Testing and Materials (ASTM) have set up certain requirements for electrodes. Thus, different manufacturer's electrodes which are within the classification established by the AWS and ASTM may be expected to have the same welding characteristics.

In this classification, each type of electrode has been assigned specific symbols such as E-6010, E-7010, E-8010, etc. The prefix **E** identifies the electrode for electric arc welding. The first two digits in the symbol designate the minimum allowable tensile strength of the deposited weld metal in thousands of pounds per square inch.

For example, the 60 series electrodes have a minimum pull strength of 60,000 pounds per square inch (4222 kg per cm²); the 70 series, a strength of 70,000 pounds per square inch (4925 kg per cm²).

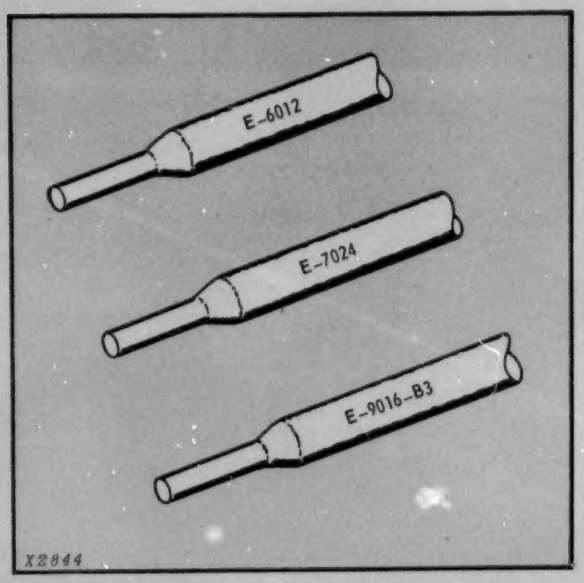

Fig. 47 — Electrode Markings

The third digit of the symbol indicates possible welding positions. Three numbers are used for this purpose: 1, 2, and 3. Number 1 is for an electrode which can be used for welding in any position. Number 2 represents an electrode restricted for welding in horizontal and flat positions. Number 3 represents an electrode to be used in the flat position only.

The fourth digit of the symbol simply shows some special characteristic of the electrode such as weld quality, type of current, and amount of penetration.

SELECTING THE ELECTRODE

Several factors are vital when choosing an electrode for welding. The welding position is particularly significant.

The table on page 31 lists the general recommendations for types of current and welding positions of some of the more common electrodes.

As a rule, never use an electrode which has a diameter larger than the thickness of the metal to be welded. Some operators prefer larger electrodes because they permit faster travel along the joint and thus speed up welding, but this takes a lot of skill.

Position and the type of joint are also factors in determining the size of the electrode. For example, in a thick metal section with a narrow vee, a small-diameter electrode is always used to run the first weld or root pass (see E, Fig. 44). This is done to insure full penetration at the root of the weld. Successive passes are then made with larger electrodes.

For vertical and overhead welding, $^{3}/_{16}$ inch (0.2 mm) is the largest diameter electrode that should be used, regardless of plate thickness. Larger electrodes make it too difficult to control the deposited metal.

For economy, always use the largest electrode that is practical for the work. It takes about half the time to deposit a quantity of weld metal from ¼ inch (6.4 mm) inch coated mild steel electrodes than from $^{3}/_{16}$ inch (4.8 mm) electrodes of the same type. The larger sizes not only allow the use of higher currents but require fewer stops to change the electrode.

Deposition rate and joint preparation are also important factors which influence the selection of electrode. Electrodes for welding mild steel are sometimes classified as fast-freeze, fill-freeze, and fast-fill (see the table). **Fast-freeze** electrodes produce a snappy, deep penetrating arc and fast-freezing deposits. They are commonly called reverse-polarity electrodes even though some can be used on AC. These electrodes have little slag and produce flat beads. They are widely used for all-position welding for both fabrication and repair work.

Fill-freeze electrodes have a moderately forceful arc and deposit rate between those of the fast-freeze and fast-fill electrodes. They are commonly called the "straight-polarity" electrodes even though they may be used on AC. These electrodes have complete slag coverage and weld deposits with distinct, even ripples. They are the general-purpose electrode for production shop and are also widely used for repair work. They can be used in all positions, though fast-freeze electrodes are preferred for vertical and overhead welding.

The **fast-fill** group includes the heavy coated, iron powder electrodes with soft arc and fast deposit rate. These electrodes have a heavy slag and produce exceptionally smooth weld deposits. They are generally used for production welding where all work can be positioned for downhand (flat) welding.

Another group of electrodes are the low-hydrogen type which contain little hydrogen in either moisture or chemical form. These electrodes have outstanding crack resistance, little or no porosity, and quality x-ray deposits.

ELECTRODE CHARACTERISTICS

Type	AWS Class	Current Type	Welding Position	Weld Results
Mild Steel	E6010	DCR	F, V, OH, H	Fast freeze, deep penetrating, flat beads,
	E6011	DCR, AC	F, V, OH, H	all-purpose welding
	E6012	DCS, AC	F, V, OH, H	Fill-freeze, low penetration, for poor fit-up,
	E6013	DCR, DCS, AC	F, V, OH, H	good bead contour, minimum spatter
	E6014	DCS, AC	F, V, OH, H	
	E6020	DCR, DCS, AC	F, H	Fast-fill, high deposition, deep groove
	E6024	DCR, DCS, AC	F, H	welds, single pass
	E6027	DCR, DCS, AC	F, H	Iron powder, high deposition, deep penetration
	E7014	DCR, DCS, AC	F, V, OH, H	Iron powder, low penetration, high speed
	E7024	DCR, DCS, AC	F, H	Iron powder, high deposition, single and multiple pass
Low Hydrogen	E6015	DCR	F, V, OH, H	Welding of high-sulphur and high carbon
	E6016	DCR, AC	F, V, OH, H	steels that tend to develop porosity and
	E6018	DCR, AC	F, V, OH, H	crack under weld deposit
	E7016	DCR, AC	F, V, OH, H	
	E7018	DCR, AC	F, V, OH, H	
	E7028	DCR, AC	F, H	
Stainless Steel	E308-15, 16	DC, AC	F, V, OH, H	Welding stainless steel 301, 302, 303, 304, 308
	E309-15, 16	DC, AC	F, V, OH, H	Welding 309 alloy at elevated temperature application and dissimilar metals
	E310-15, 16	DC, AC	F, V, OH, H	Welding type 310 and 314 stainless steel where high corrosion and elevated temperatures are required
	E316-15, 16	DC, AC	F, V, OH, H	Welding type 316 stainless steel and welds of highest quality. Contains less carbon to minimize carbon transfer in the weld. Type 316 reduces pitting corrosion
	E347-15, 16	DC, AC	F, V, OH, H	For welding all grades of stainless steels
Low Alloy	E7011-A1	DCR, AC	F, V, OH, H	For welding carbon moly steels
	E7020-A1	DCR, DCS, AC	F	
	E8018-C3	DCR, AC	F, V, OH, H	For low alloy, high tensile strength
	E10013-G	DCS, AC	F, V, OH, H	For low alloy, high tensile steels

DCR — Direct Current Reverse Polarity
DCS — Direct Current Straight Polarity

AC — Alternating Current
F — flat, V — vertical, OH — overhead, H — horizontal

Welding stainless steel requires an electrode containing chrominum and nickel. All stainless steels have low thermal conductivity. In electrodes, this causes overheating and improper arc action when high currents are used. In base metal, it causes large temperature differences between weld and the rest of the work, which warps the plate. A basic rule in welding stainless steel is to avoid high currents and high heat in the weld. Another reason for keeping the weld cool is to avoid carbon corrosion.

There are also many special-purpose electrodes for surfacing, welding copper and copper alloys, aluminum, cast iron, manganese, nickel alloys, and nickel-manganese steels. Composition of these electrodes are usually designed to match the base metal to be welded.

The basic rule in selecting electrodes is to pick one which is as close to the base metal as possible.

FOS — 52 Litho in U.S.A.

STORING OF ELECTRODES

Keep electrodes in the sealed container until ready to use them. Air and moisture in the air will combine with chemicals in the electrode covering under most conditions.

The moisture turns to steam as the electrode is heated and hydrogen in the water combines with chemicals in the covering. When mixed with the molten metal, this changes the composition of the weld, weakening it.

In summary, keep your electrodes dry.

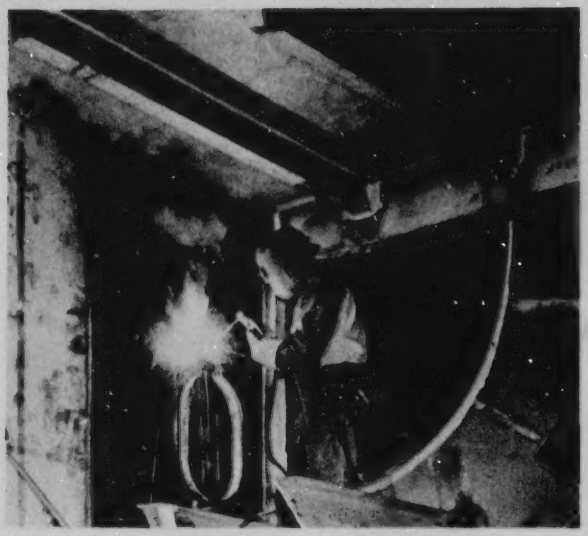

Fig. 48 — Arc Welding Operator At Work

ARC WELDING DIFFICULTIES

Symptoms	Causes	Remedies
1. *Unstable arc, moves around, arc goes out. Spatter spread over work.*	1. *Arc too long.*	1. *Shorten arc for proper penetration.*
2. *No penetration of the weld. Arc goes out often.*	2. *Too little current for size of electrode.*	2. *Increase current. Use smaller electrode.*
3. *Loud cracking sound from arc. Flux melts too rapidly. Bead wide and thin. Spatter in large drops.*	3. *Too much current for size of electrode. Could also be moisture in electrode covering.*	3. *Decrease current. Use larger electrode.*
4. *Weld remains in balls. Poor weld.*	4. *Wrong electrode for the work.*	4. *Use proper electrode for metal to be welded.*
5. *Difficulty in striking the arc. Poor penetration, making a poor weld.*	5. *Wrong polarity at electrode holder. Uncleaned metal. Too little current.*	5. *Change polarity, or use AC instead of DC current. Or, increase current.*
6. *Weak weld. Arc hard to make. Arc always breaking.*	6. *Work not clean.*	6. *Clean work, Remove all slag from previous weld.*
7. *Intermittent arc. May cause arcing at the ground clamp.*	7. *Poor ground.*	7. *Correct the poor ground. Slow down electrode movement.*

CARBON-ARC WELDING

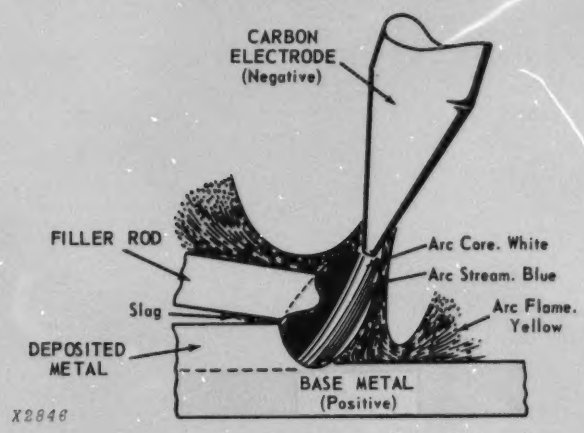

Fig. 49 — Carbon Arc Welding

This type of welding (Fig. 49) uses the heat created between a carbon electrode and the work, or between two electrodes, to melt the pieces to be welded.

In single-carbon arc welding, the arc is formed at 9500°F (5264°C) between the work and a carbon rod held in the electrode holder. The heat of the arc melts a small pool in the surface of the work to be welded. This pool is kept molten by playing the arc across it. Extra metal to form the weld is added from a separate filler rod (Fig. 49).

This type of welding cannot be used in vertical or overhead welding.

Carbon arc welding can be performed by any welding machine. The carbon arc is easier to maintain than an electrode arc. Either AC or DC welders may be used.

This type of welding has wide uses in welding, heating, bending metal, and other jobs.

GAS SHIELDED-ARC WELDING

There are two major types of gas shielded-arc welding:

- **Gas tungsten-arc welding (Tig)**
- **Gas metal-arc welding (Mig)**

Both employ a shielding gas to protect the weld zone from the atmosphere. Since the shielding gas excludes the atmosphere from the molten puddle, welded joints will more nearly possess the same chemical, metallurgical, and physical properties as the base metal. As a result, welded joints are stronger, more ductile and have less distortion than welds made by most other welding processes.

Gas shielded-arc welding particularly simplifies the joining of nonferrous metals, since no flux is needed and there is less danger of corrosion due to flux entrapment. Since the shielding gas is transparent, the operator can clearly observe the weld as it is being made. Moreover, there is very little smoke, fumes, or sparks, all of which contribute to making a neater and sounder weld. Postweld cleaning is virtually eliminated because there is no slag. This in itself results in considerable cost saving, especially where multipasses are required on a joint.

These two types of welding are widely used for heavy industrial and factory welding.

TEST YOURSELF

QUESTIONS

1. Why is a constant-current power supply with a drooping volt-amp characteristic the most adequate for arc welding?

2. Why are most welding machines rated at only 60 percent duty cycle?

3. In a DC welding supply unit, what is the direction of current flow in a straight and in a reverse polarity circuit?

4. Which polarity gives more heat at the workpiece?

5. What is arc blow and what causes it?

6. How does a rectifier differ from a transformer power supply?

7. Why should an electric arc never be looked at without proper eye protection?

8. What are the probable results if the welding current is too high or the arc length is too great?

9. How is the arc started in arc welding? (Two methods).

10. True or false? "When selecting an electrode, generally choose one which is larger than the thickness of the metal to be welded."

(Answers on page 121.)

OXYGEN AND ARC CUTTING / PART 3

Fig. 50 — Metal Cutting With A Welding Unit (Oxygen Cutting Shown)

INTRODUCTION

Metal cutting in welding is the severing or removal of metal by a flame or arc.

The most common cutting processes are:

- **Oxygen Cutting — metal is heated by gas flame and an oxygen jet does the cutting**
- **Arc Cutting — intense heat of electric arc melts away the metal**

Let's look at each type of metal cutting.

OXYGEN CUTTING

Severing metal by the oxygen or flame cutting process is possible because of the reaction of metal to oxidation. For example, when a piece of iron or steel is exposed to various atmospheric conditions, a reaction known as rusting takes place. This rusting is simply the result of oxygen in the air uniting with the metal, causing it gradually to decompose and wear away. Naturally this action is very slow but if the metal is heated and permitted to cool, heavy scales form on the surfaces, showing that the iron oxidizes much faster when subjected to heat. If a piece of steel were to be heated red hot and dropped in a vessel containing oxygen a burning action would immediately take place.

For rapid cutting of metal, you must have a device that heats the metal to a certain temperature and then delivers a blast of oxygen on the heated section. The *oxygen cutting torch* does this job.

Oxygen cutting can be used on plain carbon steels, low-alloy steels, manganese steels, and low-content chromium steels. Nonferrous metals and stainless steels or steels with a high chromium or tungsten content cannot be cut with the oxygen process, but they can be cut by the plasma and other methods, as we'll see later.

THE CUTTING PROCESS

The process of cutting is actually a progressive action, especially in cutting thick sections. The cut is started by preheating a section of metal to the ignition temperature. Oxygen is then turned on which ignites the iron or steel at the upper surface. This burning releases heat, thereby raising the temperature of the metal below the surface and melting it. The cutting oxygen now ignites the molten metal which, in turn, releases heat to the metal below. The same action progresses downward until the metal is severed.

During cutting a slag is formed. The slag is principally iron oxide (Fe_3O_4), alloying elements in the

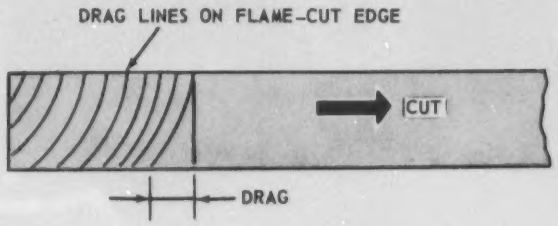

Fig. 51 — Effective Cutting Is Related To Drag

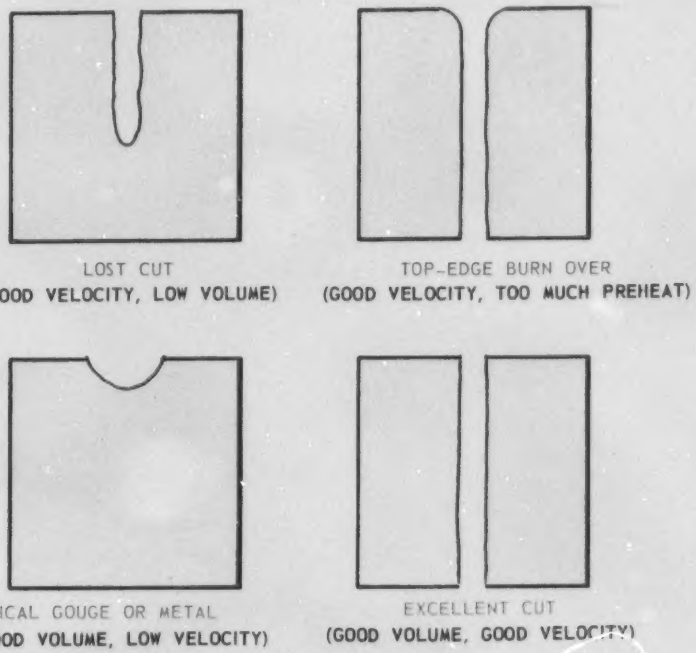

Fig. 52 — Effective Cutting Depends On The Volume Of Oxygen

iron, plus some of the pure iron itself. This slag is blown out of the cut by the force of the oxygen stream.

Effective cutting depends on the amount of oxygen supplied for combustion and the correct tip size. Once the metal is ignited, the type of fuel gas used for preheating has no influence on the cutting.

The volume of cutting oxygen has a direct relationship to the formation of what is known as **drag**. The drag of a cut is the distance between the point where the oxygen stream enters the top of the metal and the point where the slag emerges from the bottom of the cut. See Fig. 51.

Conceivably the most efficient cut is where there is zero drag, that is, no lag between the top and bottom distance of the cutting reaction. However, to achieve zero drag, a high volume of oxygen is necessary and this may not always be the most economical.

On the other hand, if the oxygen volume is low, an excessive amount of drag may develop. Too long a drag will leave uncut corners and even cause the steel fire to extinguish before the slot or kerf reaches the bottom of the metal. When the supply of oxygen is too high, the top edges of the kerf usually burn over, producing rough surface edges, and considerable waste of oxygen (Fig. 52).

Most shops, where a great deal of cutting is done, attempt to find the most economical drag for the type of cutting.

This so-called "standard drag" is generally the longest possible drag that will produce the required accuracy of cut with a minimum amount of uncut corners.

The use of a correct **tip size** is also important because it affects the speed, accuracy, and economy of the cutting process.

A tip that is *too small* will fail to generate sufficient kindling temperature to keep the cutting progressing forward.

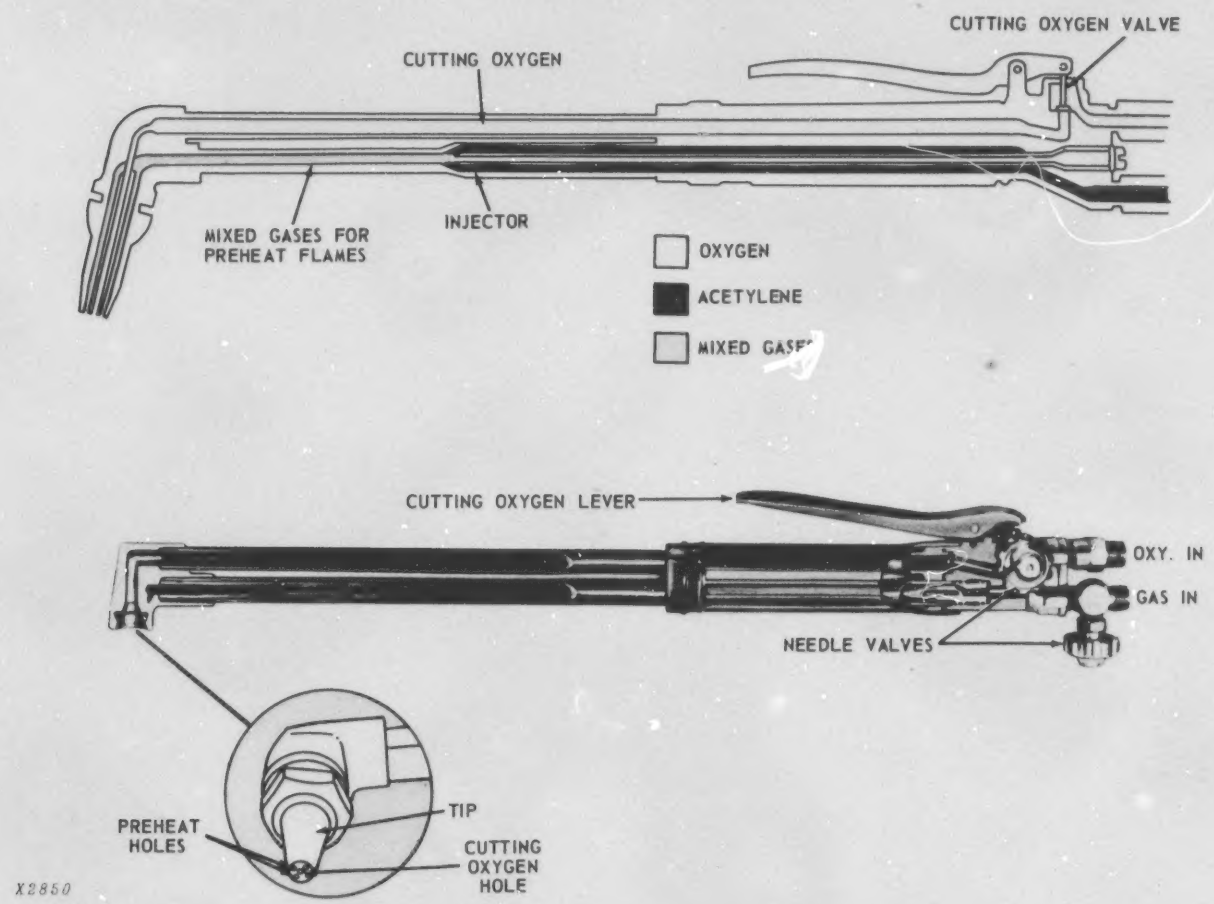

Fig. 53 — Oxy-Acetylene Cutting Torch And Tip

If the tip size is *too large*, the waste of oxygen becomes extremely high.

Orifices in cutting tips must be kept clean to produce a good flame.

FUEL GASES

The function of the fuel gas is to raise the temperature of the metal to start and continue the cutting process. Several types of gases are used for this purpose. The most common are acetylene, propane, Mapp, and acetogen.

The type of fuel gas selected depends on such factors as cost of gas, ease of handling gas containers, heat intensity of the flame, type of cutting to be done, and kind of metal to be cut.

The chart below lists the flame temperatures of different fuels for cutting purposes. Special cutting tips must be used with each type of fuel gas.

FLAME TEMPERATURES OF FUEL GASES USED FOR CUTTING

Fuel Gases	Flame Temperature
Acetylene	5,420°F (2,995°C)
Propane	5,190°F (2,868°C)
Hydrogen	4,600°F (2,540°C)
Mapp	5,301°F (2,930°C)
Acetogen	5,400°F (2,985°C)
Natural Gas	5,000°F (2,762°C)

MANUAL CUTTING

The *cutting torch* is equipped with a special lever for control of the oxygen and a cutting tip which has an orifice in the center surrounded by several smaller ones. See Fig. 53 on page 37. The center opening permits the flow of the cutting oxygen and the smaller holes are for the heating flame.

MANUAL AND MACHINE CUTTING OF CLEAN MILD STEEL (NOT PREHEATED)

Thickness of Steel, in. (mm)		Diameter of Cutting Tip Orifice, in. (mm)		Cutting Speed in. per Min. (mm per Min.)		Gas Consumptions, Ft.³ per Hour (m³ per Hour)							
						Cutting Oxygen		Acetylene		Natural Gas		Propane	
1/8	3.2	0.020-0.040	(0.5-1)	16-32	(400-800)	15-45	(0.4-1.3)	3-9	(0.08-0.25)	9-25	(0.25-0.7)	3-10	(0.08-0.3)
1/4	6.4	0.030-0.060	(0.75-1.5)	16-26	(400-660)	30-55	(0.8-1.5)	3-9	(0.08-0.25)	9-25	(0.25-0.7)	5-12	(0.14-0.34)
3/8	9.5	0.030-0.060	(0.75-1.5)	15-24	(380-610)	40-70	(1.1-2)	6-12	(0.17-0.34)	10-25	(0.3-0.7)	5-15	(0.14-0.4)
1/2	12.7	0.040-0.060	(1-1.5)	12-23	(305-585)	55-85	(1.5-2.4)	6-12	(0.17-0.34)	15-30	(0.4-0.8)	5-15	(0.14-0.4)
3/4	19	0.045-0.060	(1.2-1.5)	12-21	(305-530)	100-150	(2.8-4.2)	7-14	(0.2-0.4)	15-30	(0.4-0.8)	6-18	(0.17-0.5)
1	25.4	0.045-0.060	(1.2-1.5)	9-18	(230-455)	110-160	(3.1-4.5)	7-14	(0.2-0.4)	18-35	(0.5-1)	6-18	(0.17-0.5)
1 1/2	38	0.060-0.080	(1.5-2)	6-14	(150-355)	110-175	(3.1-4.9)	8-16	(0.2-0.45)	18-35	(0.5-1)	8-20	(0.2-0.6)
2	50	0.060-0.080	(1.5-2)	6-13	(150-330)	139-190	(3.6-5.3)	8-16	(0.2-0.45)	20-40	(0.6-1.1)	8-20	(0.2-0.6)
3	76	0.085-0.085	(1.65-2.2)	4-11	(100-280)	190-300	(5.3-8.4)	9-20	(0.25-0.6)	20-40	(0.6-1.1)	9-22	(0.25-0.61)
4	100	0.080-0.090	(2-2.3)	4-10	(100-255)	240-360	(6.7-10)	9-20	(0.25-0.6)	20-40	(0.6-1.1)	9-24	(0.25-0.7)
5	127	0.080-0.095	(2-2.3)	4-8	(100-200)	270-380	(7.6-10)	10-24	(0.3-0.7)	25-50	(0.7-1.4)	10-25	(0.3-0.7)
6	152	0.095-0.105	(2.3-2.7)	3-7	(75-180)	260-500	(7.3-14)	10-24	(0.3-0.7)	25-50	(0.7-1.4)	10-30	(0.3-0.8)
8	200	0.095-0.110	(2.3-2.8)	3-5	(75-125)	460-620	(12.9-17.4)	15-30	(0.4-0.8)	30-55	(0.8-1.5)	15-32	(0.4-0.9)
10	254	0.095-0.110	(2.3-2.8)	2-4	(50-100)	580-700	(16.2-19.6)	15-35	(0.4-1)	35-70	(1-2)	15-35	(0.4-1)
12	305	0.110-0.130	(2.8-3.3)	2-4	(50-100)	720-850	(20.2-23.8)	20-40	(0.6-1.1)	45-95	(1.3-2.7)	20-45	(0.6-1.3)

Preheat oxygen consumptions: Preheat oxygen for acetylene = 1.1 to 1.25 × acetylene flow (ft.³ per hr. or m³ per hr.); preheat oxygen for natural gas = 1.5 to 2.5 × natural gas flow (ft.³ per hr. or m³ per hr.); preheat oxygen for propane = 3.5 to 5 × propane flow (ft.³ per hr. or m³ per hr.).

Operating notes: Higher gas flows and lower speeds are generally associated with manual cutting, whereas lower gas flows and higher speeds apply to machine cutting. When cutting heavily scaled or rusted plate, use high gas flows and low speeds. Maximum indicated speeds apply to straight line cutting; for intricate shape cutting and best quality, lower speeds will be required.

11

Tip size will depend on the thickness of the metal to be cut. The chart on page 38 includes the various tip orifice sizes for different thicknesses of metal. Cutting speeds and gas consumption for each thickness of metal is also shown.

HOW TO SET UP CUTTING TORCH

Before starting to cut, observe all safety rules (see Part 8).

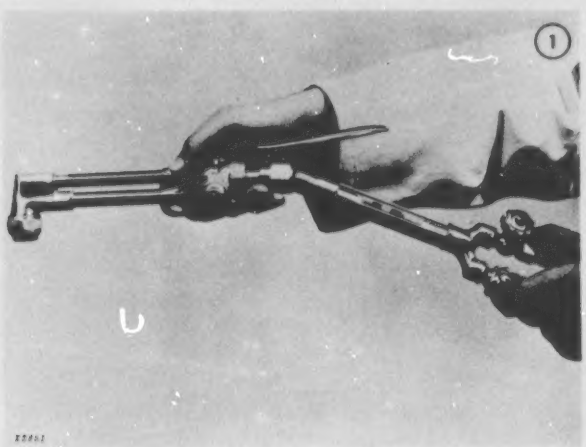

Fig. 54 — Installing Cutting Attachment On Torch

1. Attach the cutting attachment to the welding torch by holding the attachment in one hand and the welding torch in the other (Fig. 54). Tighten the fittings.

Fig. 55 — Setting Up Cutting Torch

Select the cutting tip size suitable for the job (see chart on page 38). Be sure the taper cone seat on the tip is not damaged and is free from all dirt before inserting into cutting attachment or cutting torch head.

Open the oxygen valve on the welding torch completely. The preheat oxygen is not adjusted by this valve, but by the preheat oxygen valve on the cutting attachment. Therefore, the welding torch oxygen valve must be wide open at all times to supply the attachment with both preheat and cutting oxygen.

2. Connect hoses in the same manner as for the welding torch (Fig. 55, top).

3. Secure the cutting tip into the torch head with a wrench, using firm but not excessive force.

OPERATING THE CUTTING TORCH

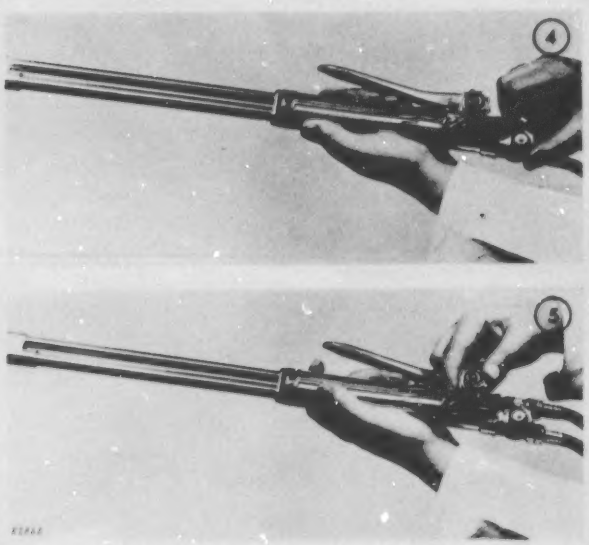

Fig. 56 — Opening The Cutting Torch Valves

4. The bottom wheel valve normally controls the flow of acetylene or fuel gas (Fig. 56, top). (This corresponds to the fuel valve on the welding torch).

5. The top wheel valve normally controls the oxygen for the preheat flames. (This is the same valve on the cutting attachment. Remember the oxygen valve on the welding torch must be *wide open*).

The lever valve controls the cutting oxygen which passes through the center hole of the tip.

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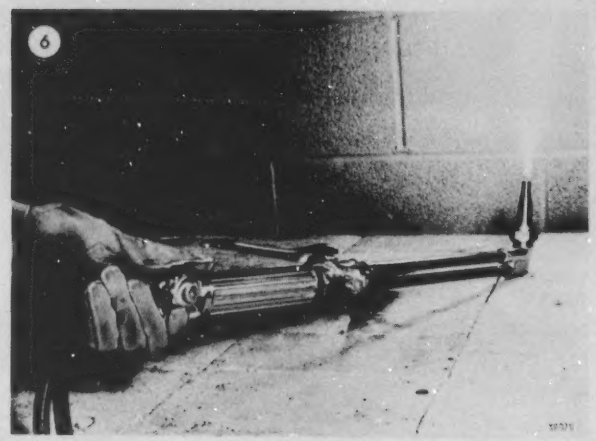


Fig. 57 — Lighting The Cutting Torch

The following procedure is for **acetylene** only.

6. Light the torch (Fig. 57).

IMPORTANT: Always purge the cutting oxygen passages by depressing the cutting oxygen lever before lighting the torch. Open the fuel valve approximately ½ turn and ignite the gas with a spark-lighter. Adjust the fuel valve until the flame clears the end of the tip about ⅛ inch (3 mm), then reduce slightly to return the flame to the tip.

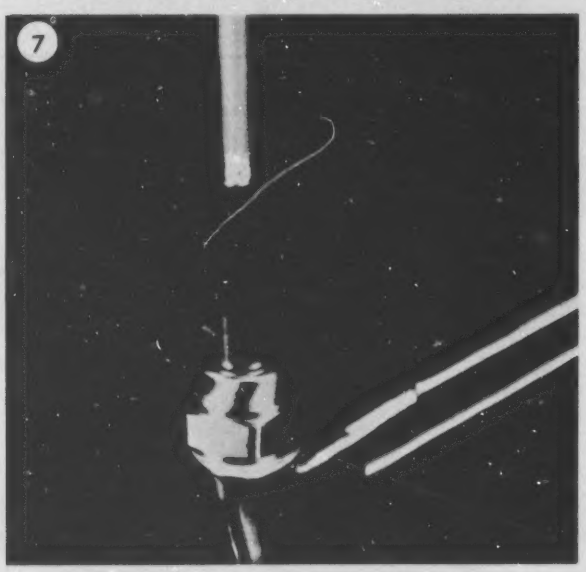
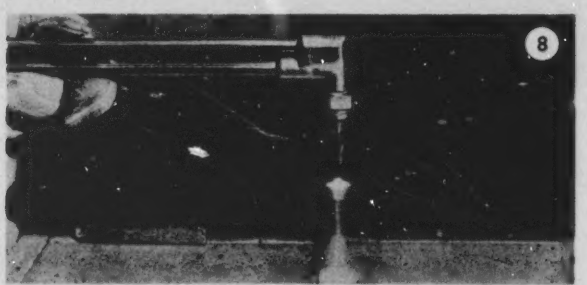


Fig. 58 — Adjusting The Cutting Torch Flame (Neutral Flame Shown)

7. Slowly open the preheat oxygen valve until a neutral flame is established (a sharp inner cone). See Fig. 58. After the neutral flame has been established, depress the cutting oxygen lever. Note that the preheat flames change slightly from neutral to a carburizing flame with a feather. With the cutting oxygen lever depressed, readjust the preheat oxygen valve until the preheat flames are again neutral as shown.

NOTE: A neutral preheat flame is shown, but often an oxidizing flame is more efficient. Follow the specific recommendations of the torch manufacturer.

HOW TO CUT



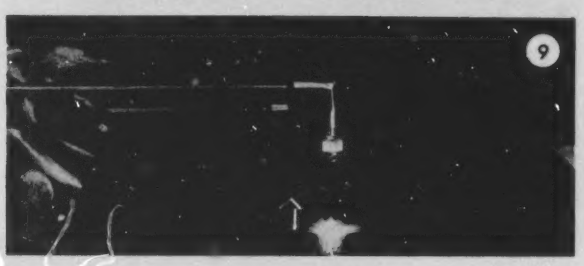


Fig. 59 — How To Cut Metal

Check to see where the molten metal and sparks will fall from cutting or welding. Serious fires and explosions have been caused by careless torch operations. TAKE ALL POSSIBLE PRECAUTIONS — have fire extinguisher available — remove or protect flammable substances, including the oxygen and acetylene hoses, before starting work.

8. Direct the preheat flames on the spot where the cut is to be started with the flames just clearing the surface. (Fig. 59, top). Take your time. Hold steady. Before the cutting action can start, the steel must be preheated to a bright cherry red. When the red spot appears, depress the cutting oxygen lever slowly.

NOTE: If the lever is depressed too soon the oxygen will chill the preheated area and prevent cutting.

9. When the cut has started, move the torch in the direction you wish to cut (Fig. 59). Moving too fast will lose the cut. Moving too slowly will make a ragged or fused cut. (The path of the cut can be marked with chalk or center punch marks.)

Hold the torch so the cone ends of the preheat flames just clear the metal. Hold the tip at right angles to the work for straight cuts or at the desired angle for bevel cuts. Take your time. Do not move too fast or too slowly. Keep the tip out of the molten metal.

Too much speed will cause the slag to emerge from the bottom and lag behind at too great an angle.

Too slow a speed will cause the edges of the cut to appear to melt and look ragged.

HOW TO PIERCE METAL

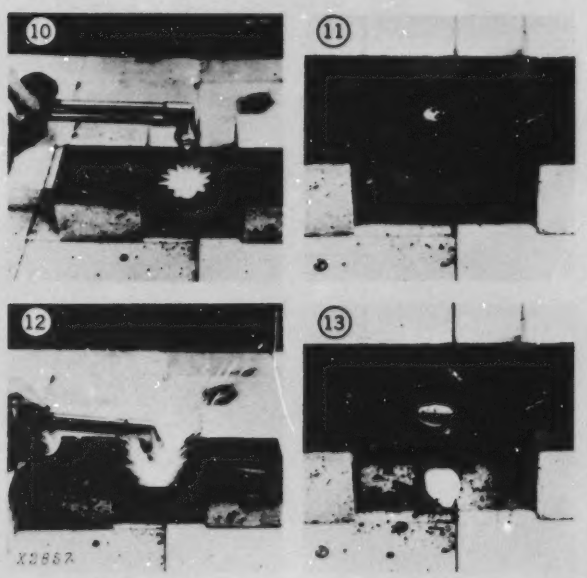


Fig. 60 — How To Pierce Metal

10-11. To pierce metal, hold the torch so the preheat flame just clears the work. When the spot becomes a bright cherry red, press down slowly on the cutting oxygen lever.

12-13. To prevent the sparks and slag from blowing toward you, tilt the torch tip slightly to one side so the sparks blow away from you and draw the torch head away slightly from the work.

When the metal is pierced, move the torch steadily in the direction you wish to cut. If the metal will not pierce all the way through, it probably means that not enough cutting oxygen pressure is being used.

For larger holes, trace the opening with a piece of chalk before you start to pierce.

STOPPING WORK

When cutting is to be stopped, close the torch acetylene valve, then the torch oxygen valve.

When the welding is to be stopped for considerable periods of time such as during lunch hour or overnight, the cylinder valve should be closed and all gas pressures released from the regulators. Follow these steps:

1. Close the oxygen cylinder valve.

2. Open the torch oxygen valve to release all pressure from the hose and regulator.

3. Turn out the pressure-adjusting screw of the oxygen regulator.

4. Close the torch oxygen valve.

5. Close the acetylene cylinder valve.

6. Open the torch acetylene valve to release all pressure from the hose and regulator.

7. Turn out the pressure-adjusting screw of the acetylene regulator.

8. Close the torch acetylene valve.

Closing the cylinder valve and then opening the torch valve relieves all pressures in the regulator and hose line. After the gauge readings (both gauges) have reached zero, the pressure-adjusting screw should always be released, since this must be done before the cylinder valve is opened again. The acetylene and oxygen pressures should not be released simultaneously and care should be taken that the release of acetylene does not create a fire hazard.

If acetylene is supplied through a hydraulic backpressure valve, first simply close the service valve. After regulators are removed from cylinders, the dust plugs should be screwed in place on the cylinder connection nuts.

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When regulators are to be out of service for several weeks or longer, it is good practice to turn in the pressure adjusting screw just enough to relieve the spring pressure on the valve seat. This aids in lengthening the life of the valve seat, especially when the seat is made of relatively soft material. Before putting the regulator into service again, the pressure-adjusting screw should be turned to the left until tension is released.

OTHER FLAME CUTTING OPERATIONS

Flame cutting is also used for stack cutting, lancing, gouging, and powder cutting.

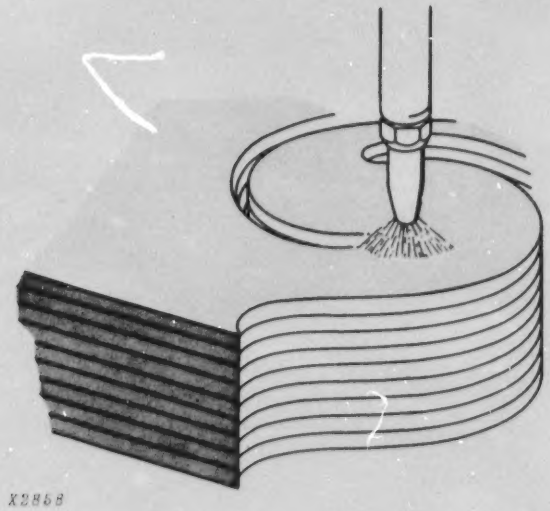

Fig. 61 — Stack Cutting

Stack Cutting

Stack cutting is the cutting of several plates simultaneously while stacked together (Fig. 61). The advantage of stack cutting is increased productivity at lower unit cost. The resulting pieces will usually have less stressed edges with squarer surfaces and fewer burrs and drag.

In stack cutting, the pieces must form a solid slab. The surfaces must obviously be free of all foreign matter and be absolutely flat. Sufficient clamping devices are often required to eliminate all air gaps between the stacked plates.

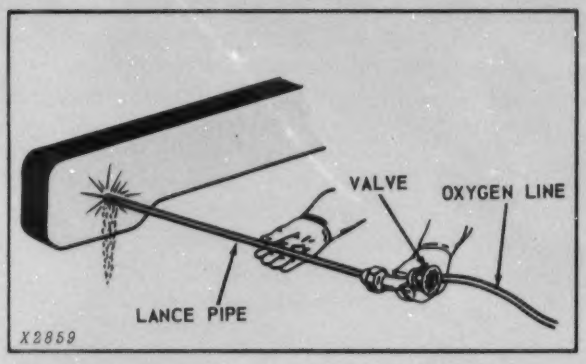

Fig. 62 — Lancing Is Used To Cut Deep Holes In Thick Metal Sections

Lancing

Lancing is used to cut a long or deep hole in a thick metal body. The lance is simply a piece of steel pipe ⅛ or ¾ inch (3 or 19 mm) in diameter equipped with a globe valve to control the flow of oxygen. See Fig. 62.

Preheating is done with a welding or cutting torch or any other means for supplying heat. As soon as the preheating is completed, the lance pipe is brought over the area where the hole is to be pierced and the oxygen turned on. The lance pipe is rotated slightly to produce a hole larger than the diameter of the lance, permitting the slag to be blown out of the hole.

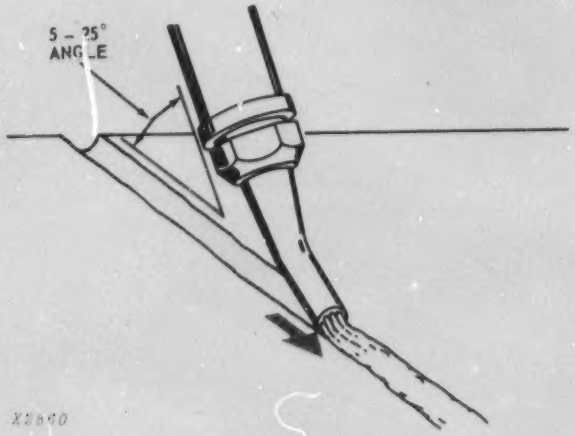

Fig. 63 — Gouging Is Used To Produce An Even Groove

Gouging

Gouging is another form of scarfing used to produce a fully controlled groove. The torch is held stationary until the correct preheat is reached and the nozzle then lowered and moved forward as shown in Fig. 63.

Powder Cutting

The regular oxygen cutting process is ineffective for cutting metals that form refractory oxides such as aluminum, bronzes, and high nickel alloys.

To cut these metals, an iron powder is fed into the oxygen stream. A mixture of iron powder and aluminum powder is sometimes used for cutting brass, copper, and high-nickel alloys. The aluminum releases more heat than just the iron powder alone. Iron powder also produces a rapid cutting action on stainless steels and is very effective in getting smoother cuts in cast iron.

Powder cutting is done with a special powder-cutting torch. The torch is equipped with a powder tube, nozzle, and powder valve. The powder is stored in a dispenser and is carried to the powder valve by compressed air or nitrogen where it is fed to the flame. In operation, the powder valve is opened first and then the oxygen valve.

ARC CUTTING

Coated mild steel electrodes, such as E-6010 or E-6011, are sometimes used for cutting. Special cutting electrodes are also available.

The diameter of the electrode will depend on the thickness of the metal to be cut and the amperage capacity of the machine. For most general cutting, $^{3}/_{32}$-inch (2.4 mm) electrodes are satisfactory for cutting metals up to ⅛ inch (3.2 mm) in thickness, and $^{5}/_{32}$-inch (4 mm) electrodes for materials which exceed ¼ inch (6.4 mm) in thickness.

Cutting with the arc is possible because of the high temperature produced by the arc. Heat of the arc ranges from about 6500° to 10,000°F (3600-5540°C) while 2600°F (1430°C) will melt steel.

SUGGESTED AMPERAGE SETTING FOR ARC CUTTING

Metal Thickness (Inch)	(mm)	Electrode Diameter (Inch)	(mm)	Ampere Range
up to ⅛	(3.2)	$^{3}/_{32}$	(2.4)	75-100
up to ⅛	(3.2)	⅛	(3.2)	125-140
over ¼	(6.4)	$^{5}/_{32}$	(4.0)	140-180

The limitation of the arc process for cutting is that it leaves a very rough, ragged edge. However, it is effective for cutting cast iron and steel for salvage purposes and in areas which are hard to reach.

The chart at left below gives the approximate ampere setting for cutting.

In a cutting operation, the metal is placed in a flat position and the cut started at the bottom edge of the plate.

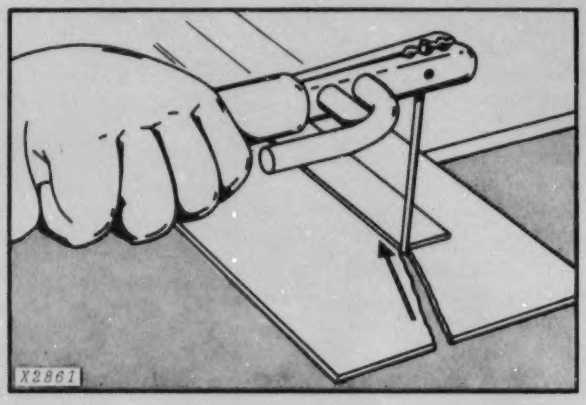

Fig. 64 — Cutting Thinner Plate With The Metallic Arc

When the diameter of the electrode is larger than the thickness of the plate being cut, the electrode is simply moved in a straight line as in Fig. 64.

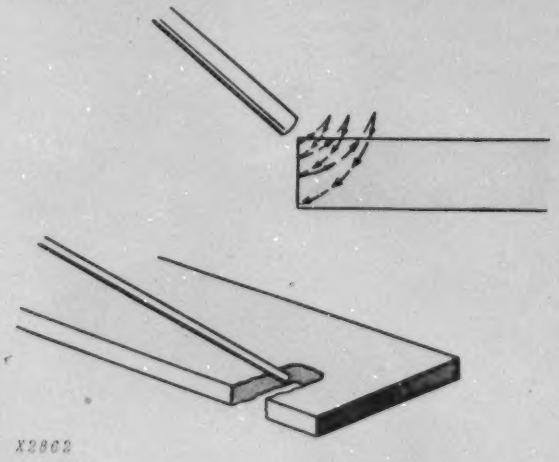

Fig. 65 — Cutting Heavier Plate With The Metallic Arc

When the material is heavier than the electrode, a weaving motion is used to make the cut. The electrode is moved upward with a quick motion and then pushed downward as shown in Fig. 65. Flat

stock over ⅛-inch (3.2 mm) thick is often easier to cut if placed in a vertical position. The cut is made from top to bottom as illustrated in Fig. 66.

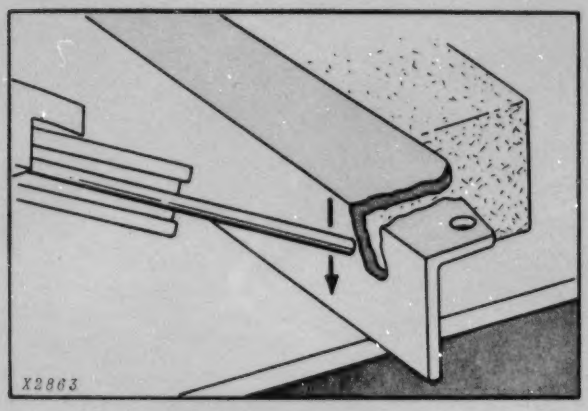

Fig. 66 — Arc Cutting Heavier Stock In A Vertical Position

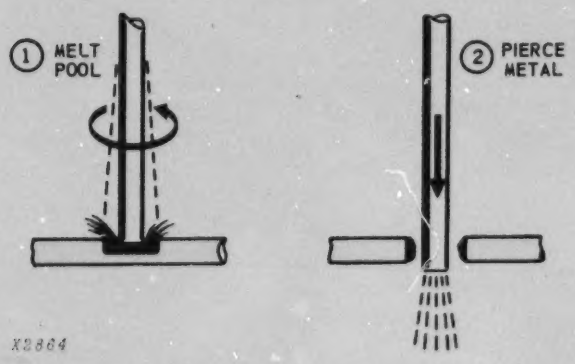

Fig. 67 — Piercing Holes With Arc

Holes can be pierced by keeping the arc over the spot until the plate begins to sweat. The arc is then brought down into the molten pool of metal and the electrode moved in a circular motion. See Fig. 67.

Piercing holes in metal over ¼ inch (6.4 mm) thick is best done with the plate in vertical position. This permits the metal to run out of the hole.

OTHER TYPES OF ARC CUTTING

Two other types of arc cutting are used today:

- **Air-Carbon Arc**
- **Plasma-Arc Cutting**

Let's look at each one in detail.

Air-Carbon Arc Cutting

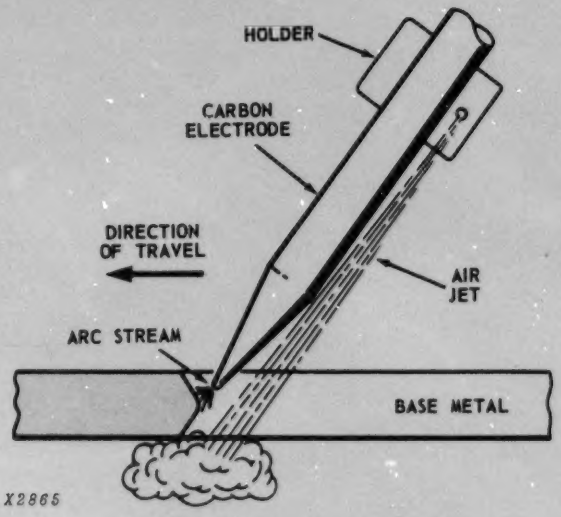

Fig. 68 — Air-Carbon Arc Cutting

A regular AC or DC welding machine and compressed air are used in the air-carbon arc cutting process. A carbon-graphite electrode held in a special holder (Fig. 68) provides the electric arc to melt the metal. As the metal melts, a jet of compressed air is directed at the point of arcing to blow the molten metal away. The compressed air line is fastened directly to the torch. The jet air stream is controlled by simply depressing a push-button valve on the holder.

Air is supplied by an ordinary compressor. In general, pressure will range from 80 to 100 psi (550-690 kPa). For light work, a pressure as low as 60 psi (415 kPa) is sufficient. Either plain or copperclad carbon-graphite electrodes can be used. Plain electrodes are less expensive; however, copperclad electrodes last longer, carry higher current, and produce more uniform cuts.

How To Cut. The torch is held so the electrode slopes back from the direction of travel. The air blast should be behind the electrode. See Fig. 68. The arc should be kept as short as possible and moved fast enough to keep up with the metal removal. The depth of the cut is controlled by the electrode angle and travel speed. For a narrow deep cut, a steep electrode angle and slow speed is used. For shallow cuts, use a flat electrode angle and fast speed.

Plasma-Arc Cutting

Plasma-arc cutting (Fig. 69) is one of the most effective processes for high-speed cutting of non-

ferrous metals and stainless steels. It cuts carbon steel up to ten times faster than any oxy-fuel and usually with greater quality and economy. For example, with ½-inch (12.7 mm) steel plate where maximum oxygen cutting speeds are under 25 inches per minute (635 mm per minute), the plasma torch produces high-quality cuts at *200* inches per minute (5080 mm per minute).

Another outstanding feature of plasma-arc cutting over oxy-acetylene cutting is its ability to sever all kinds of metals such as aluminum, copper, brass, cast iron, carbon steel, nickel, stainless steel, refractory metal, and other ferrous and nonferrous metal.

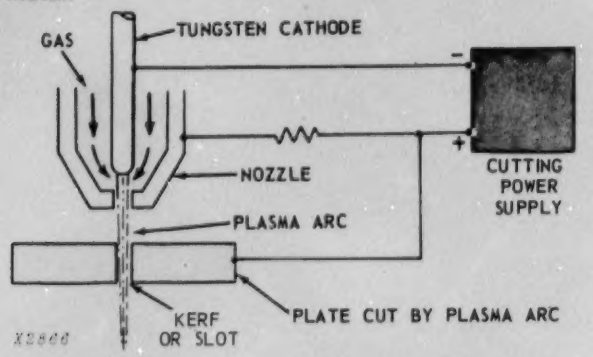

Fig. 69 — Plasma-Arc Cutting

HOW PLASMA-ARC CUTTING WORKS

In plasma-arc cutting, the tip of the electrode is located within the nozzle of the torch. The nozzle has a relatively small opening (orifice) which constricts the arc. The high-pressure gas must flow through the arc where it is heated to the plasma temperature range. Since the gas cannot expand due to the constriction of the nozzle, it is forced through the opening and emerges in the form of a supersonic jet, hotter than any flame. This heat melts any known metal and its velocity blasts the molten metal through the slot or kerf (Fig. 69).

Because transfer of heat to work is essential in cutting, the plasma torches use a transferred arc (the workpiece itself becomes an electrode in the electrical circuit). The work is thus subjected to both plasma heat and arc heat. Direct-current straight polarity is used. Precise control of the plasma jet is feasible by controlling the variable — current, voltage, type of gas, gas velocity, and gas flow (cfh).

Plasma-arc cutting is widely used in factories for mechanized welding operations.

TEST YOURSELF

QUESTIONS

1. In oxygen cutting, what is the reaction that makes possible the actual cutting process?

2. (Fill in the blanks.) In oxygen cutting, metal is heated by a ..... flame, while an ..... jet does the actual cutting.

3. What is meant by drag?

4. If too slow a cutting speed is used, what is likely to happen?

5. What is meant by stack cutting?

6. What is the limitation of the metallic arc for cutting purposes?

7. Why is it possible to cut types of metals with the plasma-arc which normally cannot be cut effectively with the oxygen process?

(Answers on page 121.)

BRAZING AND SOLDERING / PART 4

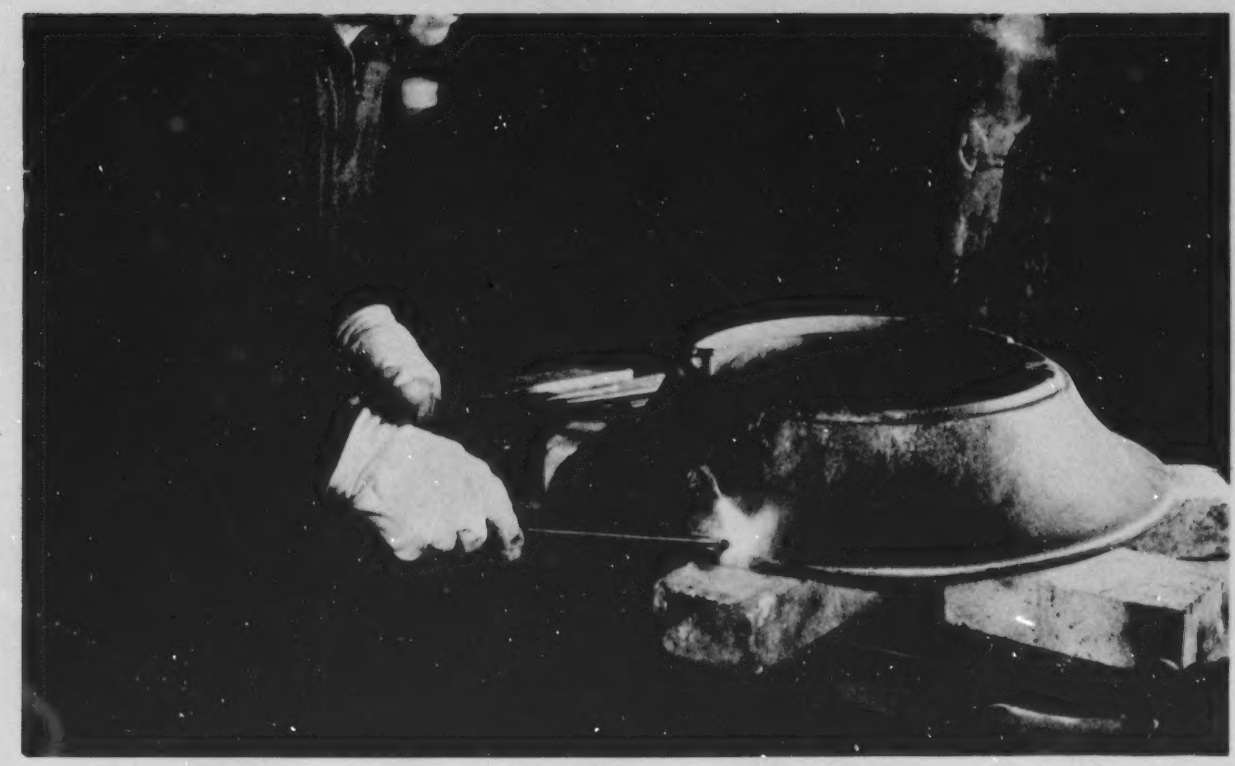

Fig. 70 — Brazing With A Torch

INTRODUCTION

Other methods besides fusion welding are often used to join metals.

The two most common processes are:

- **Brazing**
- **Soldering**

These methods are widely used in joining most metals, especially where it is not practical nor economical to use regular fusion welding.

Both *brazing* and *soldering* join metals using a filler metal which is melted between the two closely fitted metal surfaces. The major difference is that in brazing the filler metal melts at a higher temperature and fuses by capillary action, giving a stronger joint (Fig. 71).

The metal work to be joined is not melted in either process, but is only heated enough to cause the filler metal to fuse. This is what makes it different from fusion welding.

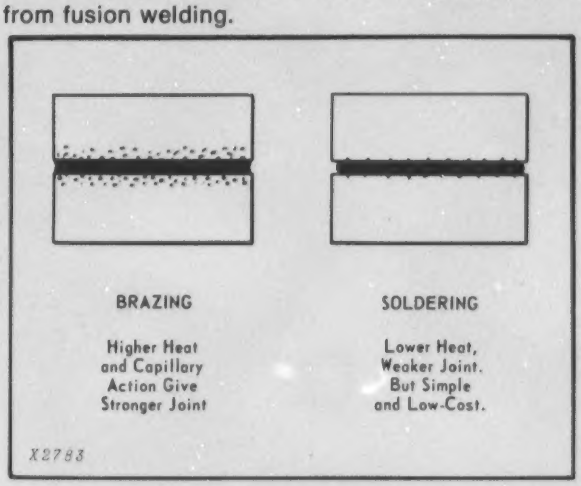

Fig. 71 — Brazing and Soldering Compared

FOS — 52 Litho In U.S.A.

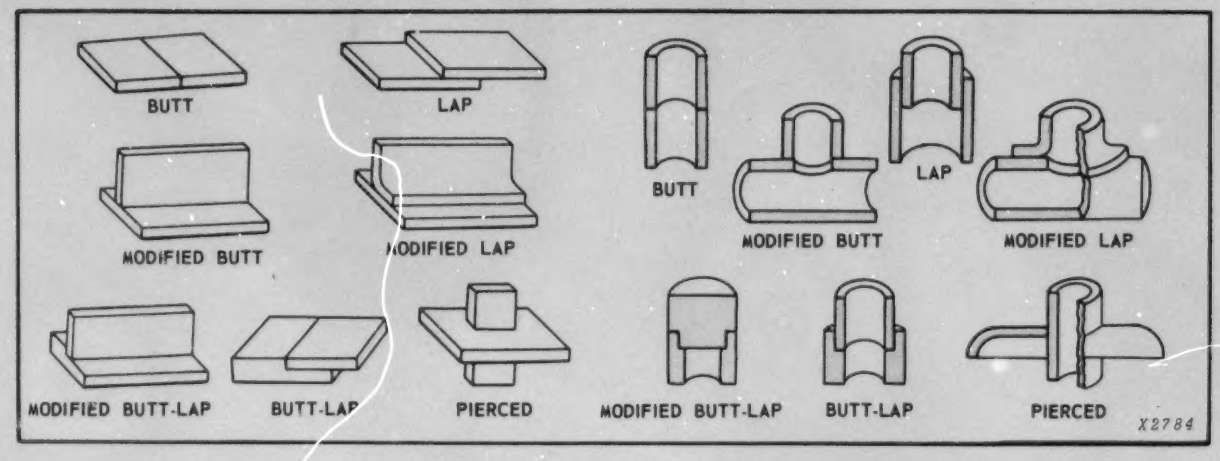

Fig. 72 — Types of Joints for Brazing

BRAZING

Brazing is a group of welding processes where metals are joined by heating to suitable temperatures above 800°F (427°C) and by using a nonferrous filler metal having a melting point below that of the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

Most commercial metals can be brazed. Although a brazed joint has a relatively high tensile strength, it is not recommended when the full strength of a joint is required.

An important factor in **brazing** is that there is *less danger of destroying the mechanical properties of the base metal* since lower bonding temperatures are used than normally required for fusion welding.

Brazing can also be used to join dissimilar metals.

REQUIREMENTS FOR BRAZING

The success of any brazing operation depends on joints having relatively small clearances and surfaces that are free of oxide and other contaminants. Cleaning is done by coating the surfaces with a special flux which when heated is capable of dissolving all foreign matter. Once the surfaces are properly fluxed, a brazing filler metal is melted at some point along the seam. Capillary action then draws the molten brazing metal between the surfaces of the joint. Upon cooling, the solidified brazing metal forms a solid bond at the joint. During heating and cooling, precautions are taken to prevent any movement of the surfaces. For most production work, a fixture is used to hold parts in alignment during brazing.

TYPES OF JOINTS FOR BRAZING

The two basic joints for brazing are the **lap** and **butt** (Fig. 72). (Tee and corner joints are considered as butt joints.)

The lap joint offers the maximum strength. The overlap should be at least three times the thickness of the thinnest section.

Since the cross-sectional area of a butt joint is limited to that of the thinnest section, maximum joint strength is impossible.

Where a lap joint cannot be used, the weakness of the butt joint can be reduced by using a scarf joint. However, the scarf joint is more difficult to prepare and often special care is required to keep the pieces in alignment.

The strength of a butt joint can also be improved by increasing the cross-sectional area as shown or by using a sleeve over the joint.

Joint clearance, which is the distance between the interface of the pieces, is an important factor in the performance of a brazed joint, whether the joint is subjected to loadings of fatigue, impact, or static. Too tight a joint may hinder the plastic flow of the filler metal, while too much clearance may prevent the full effects of the capillary action, leaving voids and uneven distribution of filler metal.

In general, joint clearance should be between 0.001 and 0.010 inch (0.025 and 0.25 mm).

BASE METALS AND RECOMMENDED FILLER METALS, BRAZING FLUXES AND APPLICATIONS

AWS Brazing Flux Type No.	Metal Combinations for Which Various Fluxes Are Suitable		Effective Temperature Range of Flux, °F (°C)	Major Materials of Flux	Physical Form	Methods of Application
	Base Metals	Filler Metals				
1	Aluminum and aluminum alloys	BAlSi	700-1190 (371-644)	Fluorides; Chlorides	Powder	1 ,2, 3, 4,
2	Magnesium alloys	BMg	900-1200 (483-650)	Fluorides; Chlorides	Powder	3, 4,
3A	Copper and copper-base alloys (except those with aluminum) iron base alloys; cast iron; carbon and alloy steel; nickel and nickel base alloys; stainless steels; precious metals.	BCuP BAg	1050-1600 (566-872)	Boric Acid, Borates, Fluorides, Fluoborate Wetting Agent	Powder Paste Liquid	1, 2, 3,
3B	Copper and copper-base alloys (except those with aluminum); iron base alloys; cast iron; carbon and alloy steel; nickel and nickel base alloys; stainless steels; precious metals.	BCu BCuP BAg BAu R B CuZn BNi	1350-2100 (733-1150)	Boric Acid Borates Fluorides Fluoborate Wetting Agent	Powder Paste Liquid	1, 2, 3,
4	Aluminum - bronze; aluminum - brass	BAg, BCuZn, BCuP	1050-1600 (566-872)	Borates Fluorides Chlorides	Powder Paste	1, 2, 3,
5	Copper and copper-base alloys (except those with aluminum) nickel and nickel-base alloys; stainless steels; carbon and alloy steels; cast iron and miscellaneous iron-base alloys; precious metals (except gold and silver).	BCu, BCuP BAg-(8-19) BAu, BCuZn BNi	1400-2200 (760-1205)	Borax Boric Acid Borates	Powder Paste Liquid	1, 2, 3.

FILLER METALS FOR BRAZING

A brazing filler metal should meet these requirements:

1. Enough fluidity so the metal will flow evenly by capillary action.

2. Good melting to form a sound metal bond.

3. Melting point consistent with the type of metal to be joined.

Brazing filler metals fall into seven groups: silver, aluminum-silicon, copper-phosphorus, gold, copper and copper-zinc, magnesium, and nickel.

The table above lists the principal metals which are joined with these filler metals.

FLUXES

Any form of oxide on the surface of a metal will prevent a uniform flow of the brazing metals. For this reason, a **flux** of some kind is necessary to eliminate the oxide. The common commercial fluxes are in paste, liquid, or powder form. Fluxes have as their main ingredients: borates, fused borax, boric acid, fluorides, chlorides, and fluborates. There is no single flux which can be used for all brazing operations. See the Table above. All traces of flux residues must be removed after brazing to prevent corrosion.

For some mass-production jobs, applying fluxes is a time-consuming task. So controlled atmospheres are used to remove oxide and prevent the formation of oxide during brazing. This method is often used with induction brazing of titanium, zirconium, and other refractory metals.

In a controlled atmosphere, a gas is continuously supplied to a furnace and circulated within it at slightly higher than atmospheric pressure. Gas may consist of high-purity hydrogen, carbon dioxide, carbon monoxide, nitrogen, argon, ammonia or some form of combusted fuel gas.

HEATING METHODS FOR BRAZING

Applying heat for brazing is done by a variety of methods depending on the kind of material to be brazed, quantity of production, and sizes of parts to be joined.

The following techniques are used:

- **Torch heating**
- **Furnace heating**
- **Induction heating**

Let's look at each method.

Torch Heating

Torch heating is probably the most common for brazing (Fig. 73). The gas mixture may be oxy-acetylene, air-gas, gas-oxygen, or oxy-hydrogen. The type of gas mixture depends on the thermal conductivity, type, and thickness of the material to be joined.

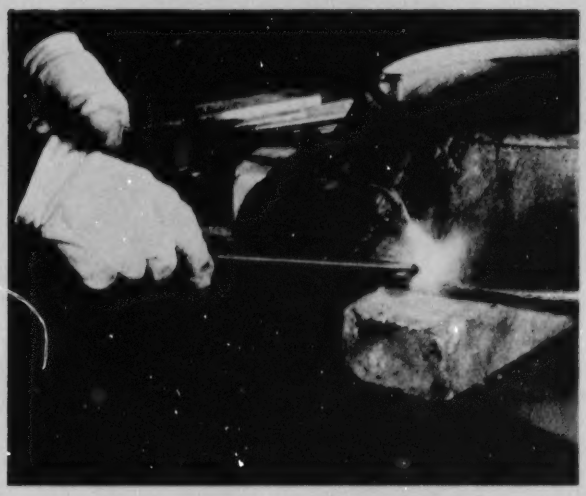

Fig. 73 — Torch Heating Is Commonly Used For Brazing

Oxy-acetylene is often more versatile for torch brazing because of its wide range of heat control. A slightly reducing flame is required and care must be taken to prevent the core of the flame from coming in contact with the metal. Close flame contact may cause the base metal to melt and restrict the flow of the brazing metal.

The *air-gas* torch provides the lowest heat and is far more adaptable for brazing thin sections. The air-gas mixture may consist of air at atmospheric pressure and city gas or air and acetylene.

The *gas-oxygen* process uses oxygen with natural gas, bottled gas, propane, or butane. This mixture produces a high flame temperature and is used where greater brazing heat is required.

The *oxy-hydrogen* torch is very useful for brazing aluminum and other nonferrous metals because of its low heat. This prevents possible overheating of the metal. Hydrogen also provides extra cleaning action and shielding during the brazing process.

Furnace Heating

Furnace heating is a production process for brazing parts that can be assembled and positioned on trays. The trays are loaded in a furnace either manually or automatically. Some automatic loading consists of a conveyor belt on which the parts are placed. The conveyor belt then moves into the furnace at regulated speeds (Fig. 74). The brazing filler metal, which can be in the form of wire, foil, powder or paste, is placed in the right position near the joint and the heat of the furnace melts the filler metal. Fluxing is used except when the heating is done in a controlled atmosphere.

Most high-production brazing in a controlled atmospheric furnace is done with hydrogen and either endothermic or combusted gas. Inert gases such as helium or argon are also used for controlled atmospheric furnace brazing.

Some furnace brazing is done in a vacuum where continuous pumping prevents oxidation and removes volatile materials that are liberated during the brazing process. Vacuum brazing has wider applications in aero-space and nuclear industries where reactive materials are joined and any form of trapped fluxes must be avoided.

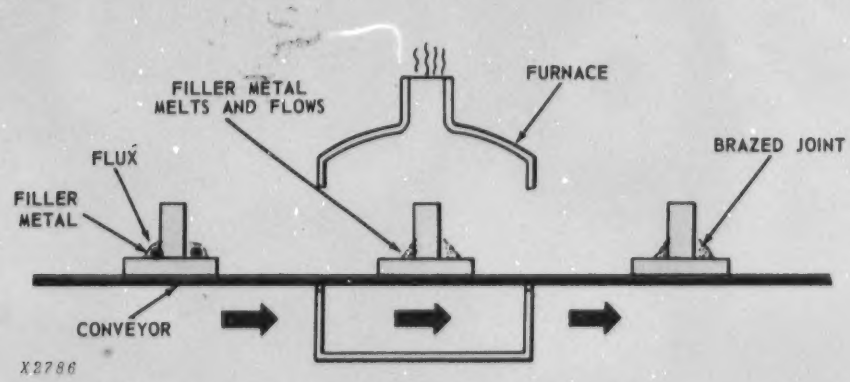

Fig. 74 — Furnace Heating For Production Brazing

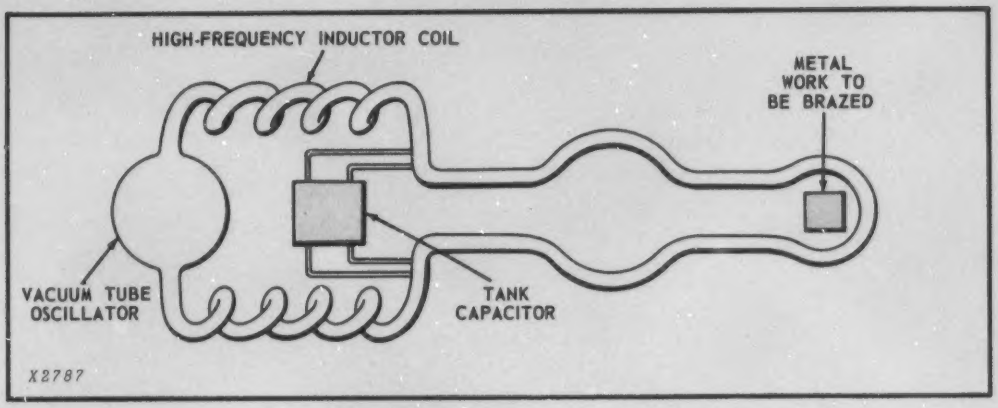

Fig. 75 — Induction Heating Coil for Brazing

Induction Heating

In this process, heat is generated by an inductor coil which is not in contact with the parts being brazed (Fig. 75).

A power supply unit converts regular line 60-cycle current into a high-frequency low voltage current.

As the current flows through the inductor coil, which surrounds the object to be brazed, a magnetic field is created. When conducting object is placed in a magnetic field, an electro-motive force is induced in the conductive material. This sets up a current and the resistance of the object to the flow of current causes instant heating to occur. The heat is relatively near the surface of the metal and any interior heating results from thermal conduction from the hot surface.

The power supply for the high-frequency current is either a motor generator, spark gap unit, or a vacuum tube oscillator.

The size of the power supply depends on the parts to be brazed and the production rate. Low-frequency power units produce deeper heating and are designed for brazing heavy sections, while high-frequency units produce light or shallow heating.

The work or inductor coil usually is of tubing but can be a copper block with an internal passage for water. The work coil has to be kept cool with circulating water. The size of the coil, that is the number of turns of copper tubing or the thickness of the copper block, is governed by the required heat zone to be developed.

Induction heating is used in brazing parts which can be aligned in a fixture and require rapid heating. It is very economical for quantity production when parts can be adapted to the induction furnace.

DIP BRAZING

There are two dip brazing methods:

1. *Molten metal bath*
2. *Molten flux bath*

Molten Metal Bath

This technique consists of immersing parts in a bath of molten brazing metal. The brazing material is melted in a crucible with a cover of flux maintained over the molten filler metal. The parts to be brazed are first cleaned and fluxed and then dipped into the bath. The process is limited to brazing small assemblies such as wire connections or metal strips when they can be easily held in fixtures.

Molten Flux Bath

Flux in the form of a chemical salt is melted in a container or flux pot by a gas flame or electrical resistance. The most common method is passing an electric current through the bath. With resistance heating, the initial charge of flux is first melted by some other heating source and the molten salt poured into the fluxing container. Once the flux is in a molten state the resistance of the bath to the electrical current provides sufficient heat to keep the flux at the proper temperature. A thermocouple immersed in the molten bath and a temperature control unit keeps the molten flux at the required brazing heat.

The parts to be brazed are cleaned and assembled in a suitable fixture. Brazing filler metal in the form of rings, washers, slugs or paste mixture is preplaced on the base metal. In production brazing with molten salts, the parts and holding fixtures are usually pre-heated in a furnace to a tempera-

ture near the melting point of the molten flux. The parts are then dipped in the molten flux where the heat is sufficient to melt the brazing material.

Molten flux bath dip brazing is often used to fabricate radiators or other cooling units.

BRAZE WELDING

Braze welding is slightly different from regular brazing. While brazing is the joining of two surfaces by a thin bond of brazing metal, braze welding is much like fusion welding except that the base metal is not melted. The base metal is brought up to its tinning temperature and then a weld bead is deposited over the seam with a filler rod.

Although the base metal is never actually melted, the bond formed by the brazing metals are often comparable to those secured through fusion welding.

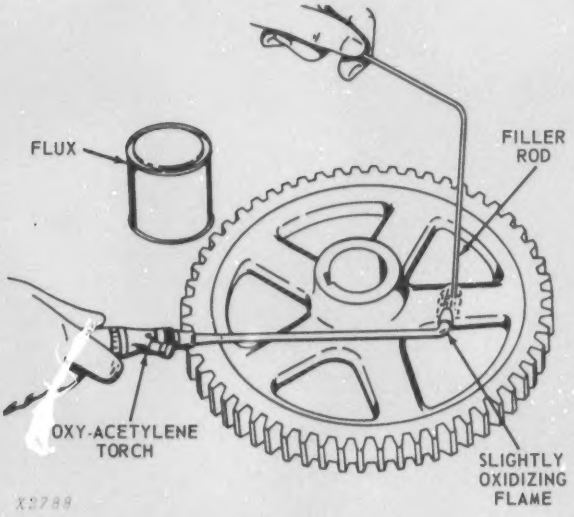

Fig. 76 — Braze Welding

Bronze welding is a typical braze welding operation. This technique is frequently used for joining or repairing such metals as cast iron, malleable castings, copper, brass, and various dissimilar metals. See Fig. 76. The bronze filler rod which is applied to the seam consists of copper and zinc with small quantities of tin, iron, maganese, and silicon.

The welding procedure involves cleaning the surface and then applying a coating of flux to diffuse the oxide. The flux is applied by dipping the heated rod into the powdered flux. The flux can also be mixed with water and spread over the seam.

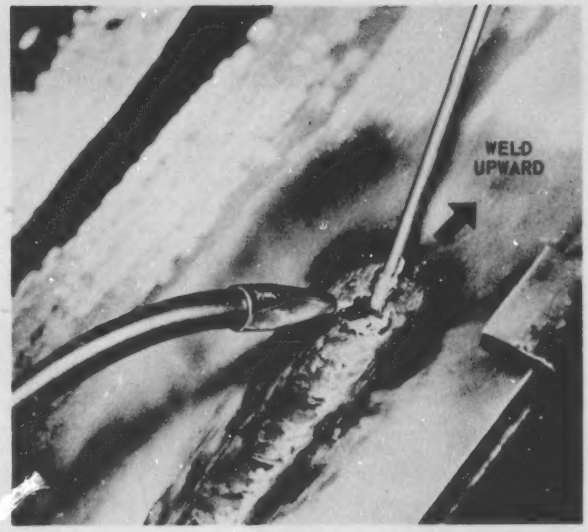

Fig. 77 — In Bronze Welding, The Weld Should Travel Upward At An Incline

Any type of joint is suitable for bronze welding. On thick sections, the edges should be beveled to form a 90-degree V-groove. The work is positioned so the weld travels upward on an incline (Fig. 77). In this position, the molten bronze cannot flow ahead of the heated welding area and the surface in front of the weld is left open to heating.

Generally, bronze welding is performed with an oxy-acetylene torch with a frame that is *slightly oxidizing*. The flame is concentrated on the starting end until the metal begins to turn a dull red color. A small amount of bronze is melted on the surface and allowed to spread along the entire seam. The flow of this thin film of bronze is known as the tinning operation. Unless the surfaces are tinned properly, the remaining bronzing cannot be done successfully.

If the surface of the metal is heated properly, the bronze should spread out evenly over the metal. A surface that is too hot will cause the bronze to bubble or run around like drops of water on a warm stove. When the bronze forms into balls which tend to roll off, the base metal is not hot enough.

Once the base metal is well tinned, a weld bead is deposited over the seam using a slight circular torch motion. The rod must be constantly dipped into the flux as the weld progresses.

BRAZING WITH CARBON ELECTRODES

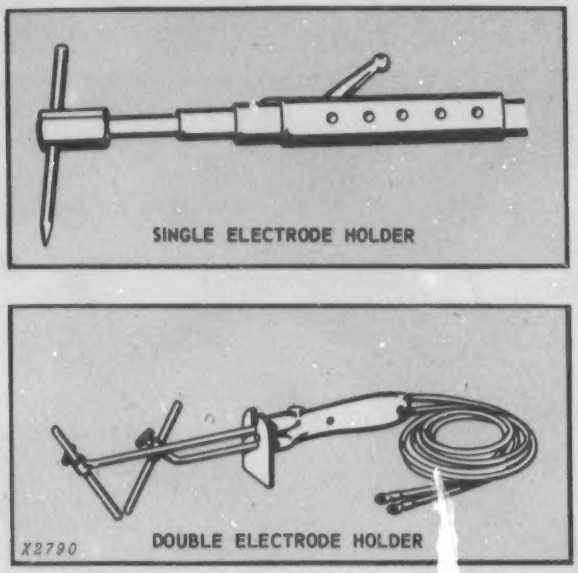

Fig. 78 — Carbon-Arc Electrode Holder

Some brazing is performed with a carbon-arc. The process is very similar to the metal electrode arc except that the electrode does not melt or provide filler metal. Here the carbon electrode serves only as the medium of generating the arc. The electrode is either of pure graphite or in the form of a copper-coated carbon and held in a special holder (Fig. 78).

The regular metal electrode holder is not suitable since the carbon electrode becomes very hot and the intense heat soon ruins the ordinary holder. A shield is often located near the handle to protect the operator's hand from the heat. The handle of the holder is made so air can circulate around it and keep it cool. When the carbon-arc is used for continuous operations, the holder is often water-cooled.

The electrode for brazing is shaped by grinding it to a long tapering point. See Fig. 79.

Either a DC or AC power source can be used for brazing. With an AC unit, the arc is formed between two carbon electrodes held in a holder as shown in Fig. 78. In the single carbon electrode with DC current, the machine must be set for straight polarity. Reverse polarity produces too much of an unstable arc and causes greater quantities of vaporized carbon to enter the molten brazing material.

Brazing is done by striking an arc and feeding a brazing rod into the arc. Most carbon arc brazing is done with a bare silicon bronze rod. The filler rod is held as illustrated in Fig. 10 and moved along the surface with the arc over the rod.

With the AC holder, the formed arc between the two electrodes remains intact even though the electrodes are withdrawing from the work. The arc is established by moving the electrodes with a push button located on the holder until the electrodes touch. Pressure on the button is then released to permit the points of the electrode to part and establish the arc. When the distance between the two electrodes is correct, there will be a quiet, soft flame. Striking the arc with a DC current is done in the same way as in metal electrode-arc welding.

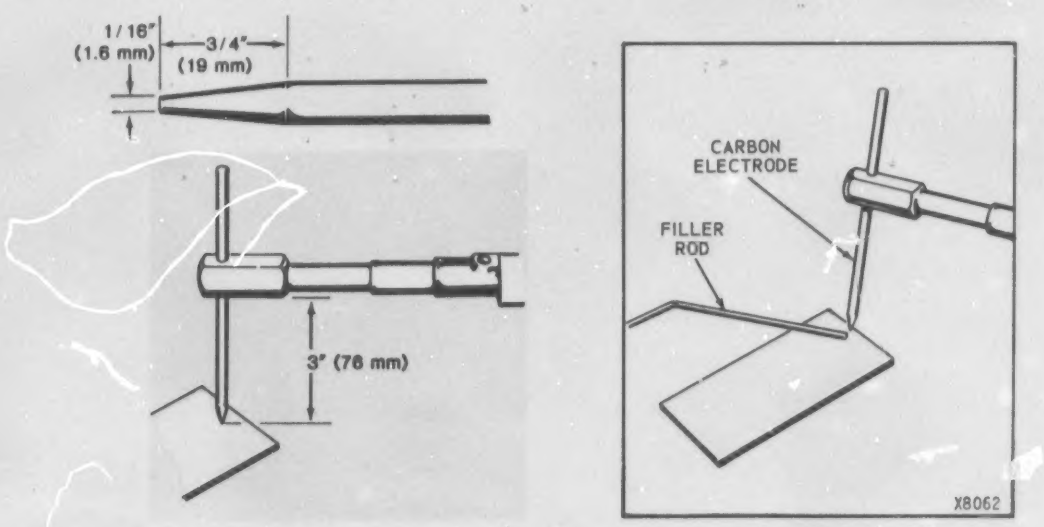

Fig. 79 — Brazing With The Carbon-Arc

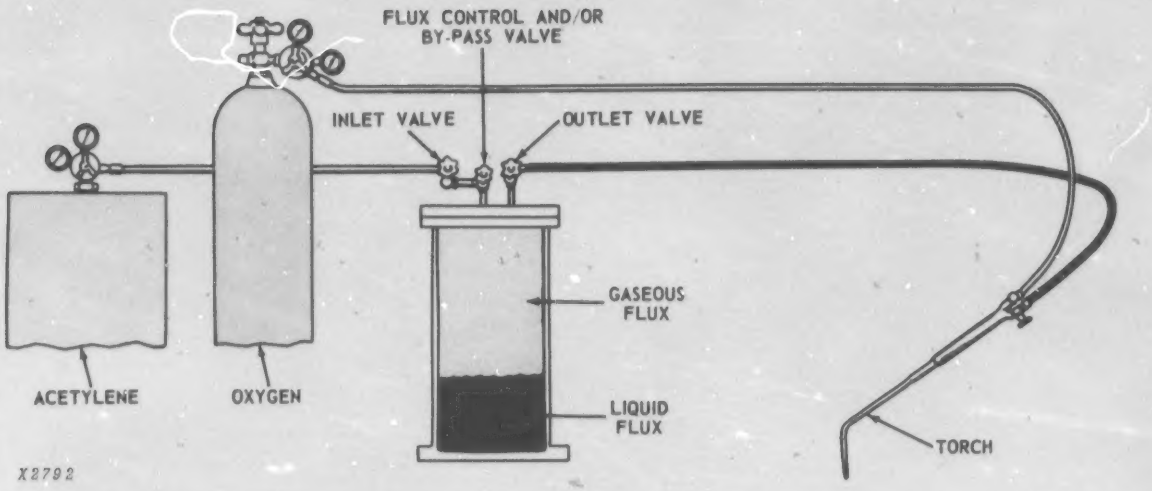

Fig. 80 — Brazing With A Liquid Flux

BRAZING WITH A LIQUID FLUX

Liquid flux eliminates the need of applying flux to metal surfaces before beginning the actual brazing operation.

A liquid fluxing material is placed in a separate tank that is connected to the regular gas line (Fig. 80). The flow of gas into the tank vaporizes the flux and induces it into the gas stream where it passes through the welding torch and into the flame. As the flame contacts the metal, the flux in the flame cleans and fluxes the surface for brazing. No pre-cleaning or post-cleaning of the parts is necessary.

As a rule, less heat is required with liquid flux than when a powder or wet flux is used. The weld metal is not oxidized and the strength of the brazed joint is greater.

Except for the fluxing tank, no other special equipment is needed as a standard welding torch is utilized.

The tank is equipped with a three-valve control unit. The inlet valve regulates the entry of gas into the tank, the flux or bypass valve controls the amount of flux used or eliminates the flux entirely, and the outlet valve supplies the flux gas through the line of the torch. See Fig. 80.

Liquifluxer can be used for brazing brass, bronze, copper, cast aluminum, cast and malleable iron, nickel and steel.

Fig. 81 — Soldering With A Torch

SOLDERING

Soldering is the joining of two metal pieces by using a nonferrous filler metal which melts below 800°F (427°C), or below those of the base metal. The filler metal is called solder and is distributed between the surfaces by capillary action.

Soldering is used to join surfaces not under high-strength forces, since solder has a relatively low tensile strength. Soldered joints are also not suitable where temperatures approach the melting point of solder.

Soldering is a simple operation, providing five basic requirements are observed:

1. The right type and amount of solder and flux are used for the base metal being joined.

2. The pieces being soldered fit tightly together.

3. The pieces are absolutely clean.

4. The pieces are held together until the solder solidifies.

5. The correct amount of heat is applied to the seam.

See the Chart on the next page for metals which can be soldered.

SOLDERS

Most soft solders are alloys of tin and lead. The percentage of each metal determines its melting point and other characteristics. The melting range is from about 370°F (188°C) for a mixture of 70 percent tin and 30 percent lead to about 590°F (310°C) for 5 percent tin and 95 percent lead.

The most common general-purpose solder is known as half-and-half or 50-50 solder. It contains 50 percent tin and 50 percent lead and melts at about 471°F (244°C).

A variety of other alloys are used for soldering purposes. See the Chart on the next page for composition of solders.

In general, alloys with a low-tin content have higher melting points and do not flow as readily as the high-tin alloys. The low-tin alloys are less expensive and are used where large volumes of soldering are done. Solders with a high amount of tin have better wetting properties and produce less cracking. High-tin solders are used considerably in electrical work.

Solders with a tin content of 60 percent or more are classified as fine solders and are used in soldering instruments where temperatures are critical.

Many commercial types of metals can be soldered. The chart below lists the various metals which are recommended or not recommended for soldering.

METALS AND SOLDERING

Base Metal, Alloy or Applied Finish	Flux Requirements			
	Non-Corrosive	Corrosive	Special Flux and or Solder	Soldering Not Recommended
Aluminum			X	
Aluminum-Bronze			X	
Beryllium				X
Beryllium Copper		X		
Brass	X	X		
Cadmium	X	X		
Cast Iron			X	
Chromium				X
Copper	X	X		
Copper-Chromium		X		
Copper-Nickel		X		
Copper-Silicon		X		
Gold	X			
Inconel			X	
Lead	X	X		
Magnesium			X	
Manganese-Bronze (High Tensile)				X
Monel		X		
Nickel		X		
Nichrome			X	
Palladium	X			
Platinum	X			
Rhodium		X		
Silver	X	X		
Stainless Steel			X	
Steel		X		
Tin	X	X		
Tin-Bronze	X	X		
Tin-Lead	X	X		
Tin-Nickel	X	X		
Tin-Zinc	X	X		
Titanium				X
Zinc		X		
Zinc Die Castings			X	

Special solders are also available. Thus a tin-antimony solder is designed to solder food-handling vessels where lead contamination must be avoided. Tin-zinc solders are intended primarily for joining aluminum. Lead-silver solders are used where strength at high temperatures is required.

Solders are available in bar, cake, solid wire, flux-core wire, ribbon and paste forms. Flux-core wire solder has an acid or resin flux in the center of the wire. With these solders, no additional flux is needed.

COMPOSITION OF ASTM SOLDERS

ASTM Number	Composition %				Melting Range
	Tin	Lead	Antimony	Copper	
5A	5	bal.	0.12 max.	0.08	572-596
5B	5	bal.	0.50 max.	0.08	572-596
10B	10	bal.	0.50 max.	0.08	514-573
20B	20	bal.	0.50 max.	0.08	364-535
20C	20	bal.	1.0-1.2	0.08	364-535
30A	30	bal.	0.25	0.08	361-477
30B	30	bal.	0.50	0.08	361-477
40A	40	bal.	0.12	0.08	361-455
50A	50	bal.	0.12	0.08	361-421
60A	60	bal.	0.12	0.08	361-374
63A	63	37	0.12	0.08	361-361

FLUXES

Oxides and rust will form on surfaces of most metals when exposed to air. Solder will not adhere if such impurities are present. By applying a flux, the oxide is removed and the formation of new oxide during the soldering process is prevented. Fluxes also increase the wetting action, allowing the solder to flow more freely.

Fluxes come in paste, liquid, powder, and cake form. Some are general-purpose fluxes usable on most all metals. Others are special fluxes such as those for aluminum soldering.

All fluxes are classified as *corrosive* or *noncorrosive*. Although the corrosive types are most effective, they must be washed from the metal after soldering. They should never be used for electrical or electronic work.

Resin is the most common noncorrosive flux. Zinc chloride is the most frequently used corrosive flux.

HEATING TOOLS

In any soldering operation, both pieces of metal to be joined must be hot enough to melt the solder. A strong bond is achieved only if the molten solder spreads evenly over the surface. A number of devices are available for heating purposes. The type used depends on the size and shape of the assembly. The major types of heating tools are:

1. **Soldering coppers**
2. **Electric soldering tools**
3. **Flame-heating devices**

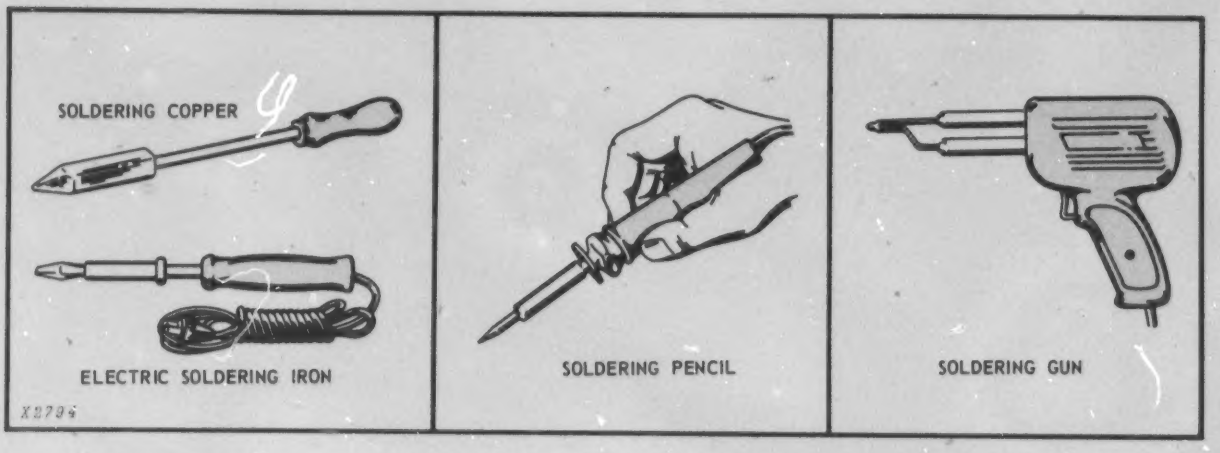

Fig. 82 — Heating Tools For Soldering

Soldering Coppers

A soldering copper consists of a forged piece of copper fastened to an iron rod with a wooden handle on one end. These coppers vary in size with heads forged in several shapes. See Fig. 82.

Generally, a lightweight copper is used for soldering light-gauge metal and a heavyweight copper for soldering heavy-gauge metal. A lightweight copper on heavy metal does not hold enough heat to heat the metal or allow the solder to flow smoothly. Soldering coppers are heated in a furnace or with a torch.

Electric Soldering Tools

These devices are often more convenient than soldering coppers because they maintain a uniform heat. See Fig. 82. They vary in sizes from 25 watts to 550 watts.

Lightweight, low-voltage *irons* with replaceable heating elements and tips are called *soldering* pencils and are preferred for electrical and electronic work. Electric soldering *guns* produce instant heat at the tip of a long small point when the trigger is pulled. On most guns, the trigger also turns on a light which focuses at the point. For these reasons, the soldering gun is very popular for electronic work.

Flame-Heating Devices

Some soldering operations are impossible or very difficult to perform with a soldering copper iron. For these jobs, a flame is used as the source of heat. See Fig. 83.

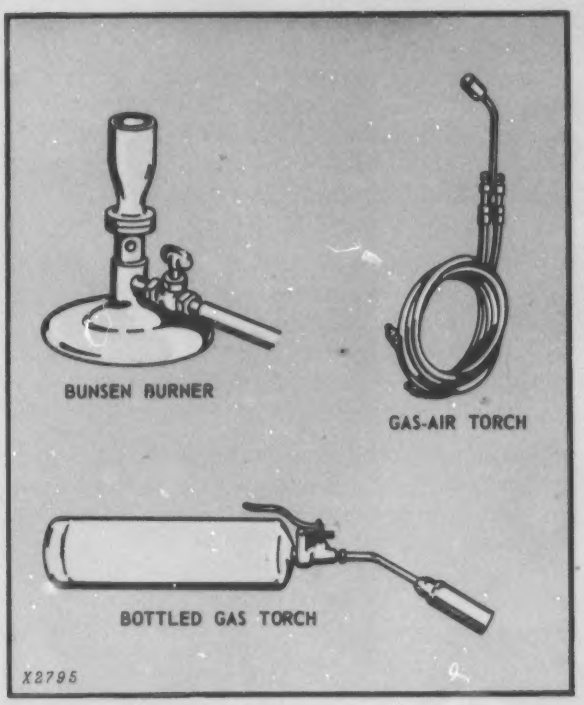

Fig. 83 — Flame-Heating Devices For Soldering

The flame is produced either with an ordinary *Bunsen burner* or a *gas torch,* depending on the nature of the job.

The most efficient, safe, and versatile gas torch is one that burns city gas and compressed air. These torches are often equipped with changeable tips which can produce a wide range of flame sizes. The gas-air torch has two needle valves; one valve controls the pressure of gas and the

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other valve the compressed air. To light the torch, the gas-needle valve is opened slightly and ignited. Then the oxygen valve is turned on and adjusted until a blue flame results. The length of the flame is controlled by the amount of gas and air allowed to flow to the tip.

Bottled-gas torches are also used for soldering, especially when the work is not at a fixed station where a gas-air torch is available. The bottled-gas torch must be operated with care; follow the manufacturer's instructions carefully.

PREPARING TO SOLDER

1. **Parts to be soldered must fit perfectly** so the solder can travel by capillary action between the two surfaces. Solder will cease to flow where there is a gap between the two workpieces.

2. **Parts to be soldered must be absolutely clean** because the solder will not stick to a dirty, oily or oxide-coated surface. Dirt and grease can be removed with a cleaning solvent. Steel wool or other abrasive cloth is used to eliminate the oxide. Applying a flux completes the cleaning and keeps the metal free from oxide during heating and soldering.

3. **Parts must be held together** during soldering so there is no movement. Any movement during the heating will cause the pieces to be misaligned and the slightest disturbance of the solder as it solidifies will cause it to crystallize. The result is a weak joint.

4. **Parts to be soldered must have a suitable joint design** to withstand the loads imposed on it. The strength of the joint cannot depend on the bond itself because a soldered joint, for example, will seldom develop shear strength greater than 250 psi (1725 kPa). If greater strength is needed, make some type of mechanical joint by lapping or folding before you solder.

TINNING A COPPER

The point of a soldering copper must be covered with a thin coat of solder to operate properly. A tinning operation is performed by first smoothing the surfaces of the point with a file and then heating the copper until it is hot enough to melt solder. The point is next rubbed on a block of sal ammoniac and a small amount of solder melted during the rubbing action (Fig. 84).

Tinning can also be done by dipping the point in a liquid or paste flux and applying solder.

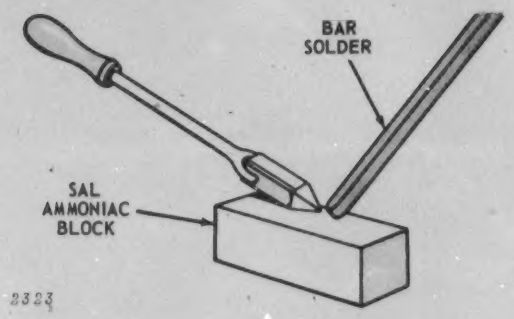

Fig. 84 — Tinning A Soldering Copper Over A Block Of Sal Ammoniac

SWEAT SOLDERING

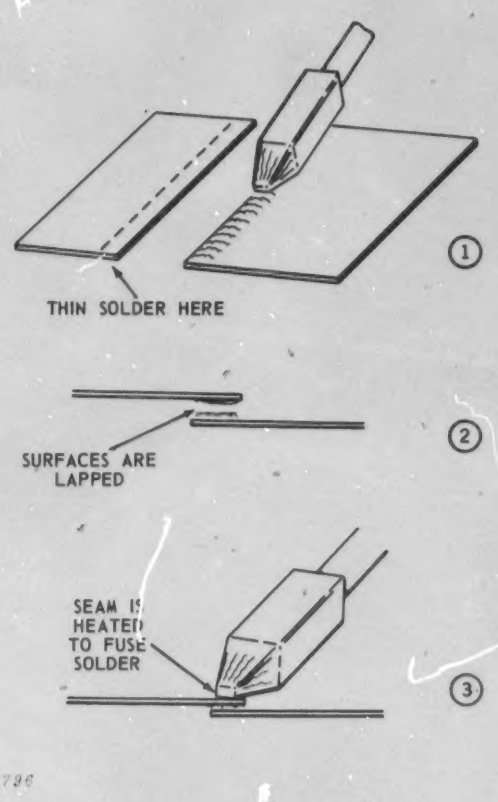

Fig. 85 — Sweat Soldering A Joint

In this process, two surfaces are soldered without the solder being visible. This is done by applying a coating of solder to each of the surfaces to be joined (1, Fig. 85). The coated surfaces are then placed together (2) and a heated copper held over the seam (3). To avoid smearing the exposed sur-

faces of the metal with solder, the excess solder on the copper is removed by quickly wiping the joint with a damp cloth.

When the solder between the two surfaces begins to melt and show evidence of flowing out from the edges, pressure is applied on the metal. As the copper is drawn slowly along the seam, pressure must be maintained until the solder solidifies.

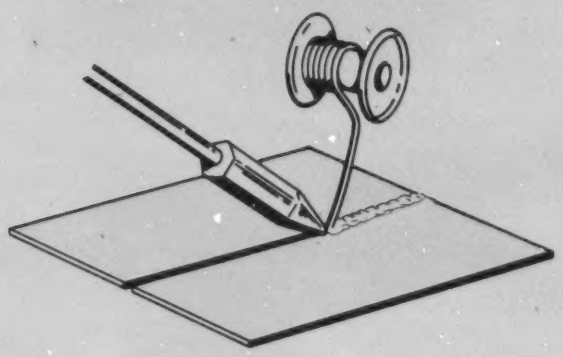

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Fig. 86 — Seam Soldering A Joint

SEAM SOLDERING

Seam soldering is running a layer of solder along the outside edge of the joint (Fig. 86). As a rule, the surfaces of the joint are first tacked to hold them in position. Tacking is done by depositing a small drop of solder at several places on the seam. The point of the copper is then moved along the edge of the seam as shown and solder applied directly in front of the point.

FLAME SOLDERING

Many soldering jobs are difficult when using a soldering copper or electric-soldering iron. In these cases a torch flame is often more practical, especially where fast soldering is required. The flame can be adjusted to the required size and directed to the exact spot where it is needed and moved to heat both pieces properly as well as to melt the solder.

INDUCTION SOLDERING

This is used where large-scale production is involved and the pieces can be kept in alignment by a fixture.

Induction heating is produced by a motor generator, spark-gap unit, or vacuum tube oscillator and the rate of heating is governed by the amount of induced current that flows.

The pieces to be soldered are aligned near the induction work coil with the solder preplaced on the joint. Cleaning and fluxing must be completed before soldering is started.

Solders for induction heating should spread rapidly and have good capillary flow. Preforms combining solder and flux are the best means of supplying the correct amount of solder and flux for induction soldering.

RESISTANCE SOLDERING

Here the electrical resistance of the metal provides the necessary heat for soldering. The work to be soldered is placed between a ground and one or two movable electrodes. Solder is fed directly into the joint when the surfaces of the workpieces reach the proper temperature.

DIP SOLDERING

Dip soldering consists of a pot with molten solder. The joint to be soldered is simply dipped into the molten solder. The bath supplies both the heat and solder to complete the soldering operation.

This soldering technique is very economical since an assembly with several joints can be soldered at once.

Any dip soldering operation requires suitable jigs and fixtures to keep the unit in alignment until the solder has solidified. These fixtures must be well made to prevent movement of the parts during the operation when they are being dipped and handled.

OVEN SOLDERING

Gas or electric ovens are used for soldering when the entire assembly can be heated without damaging any of its components. Since the assembly must be moved before and during the solidification of the solder, suitable jigs and fixtures are required to hold parts together. Without proper clamping, the joint will fail because solder is easily disturbed before it becomes solid.

TEST YOURSELF

QUESTIONS

1. How does brazing differ from regular fusion welding?

2. In some instances, why is brazing preferred over fusion welding?

3. Why is a flux required for brazing?

4. What three types of heating devices may be used for brazing?

5. In brazing with the carbon arc, how does the carbon electrode for DC current differ from the one used with AC power supply?

6. What is the difference between braze welding and regular brazing?

7. When is soldering *not* recommended for joining metals? (Give one example.)

8. (Fill in the blanks.) Most solders are alloys of ..... and .....

9. What is the advantage of an electric soldering iron over the soldering copper?

10. What is meant by tinning a copper?

11. How does sweat soldering differ from seam soldering?

(Answers on page 121.)

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METAL SURFACING / PART 5

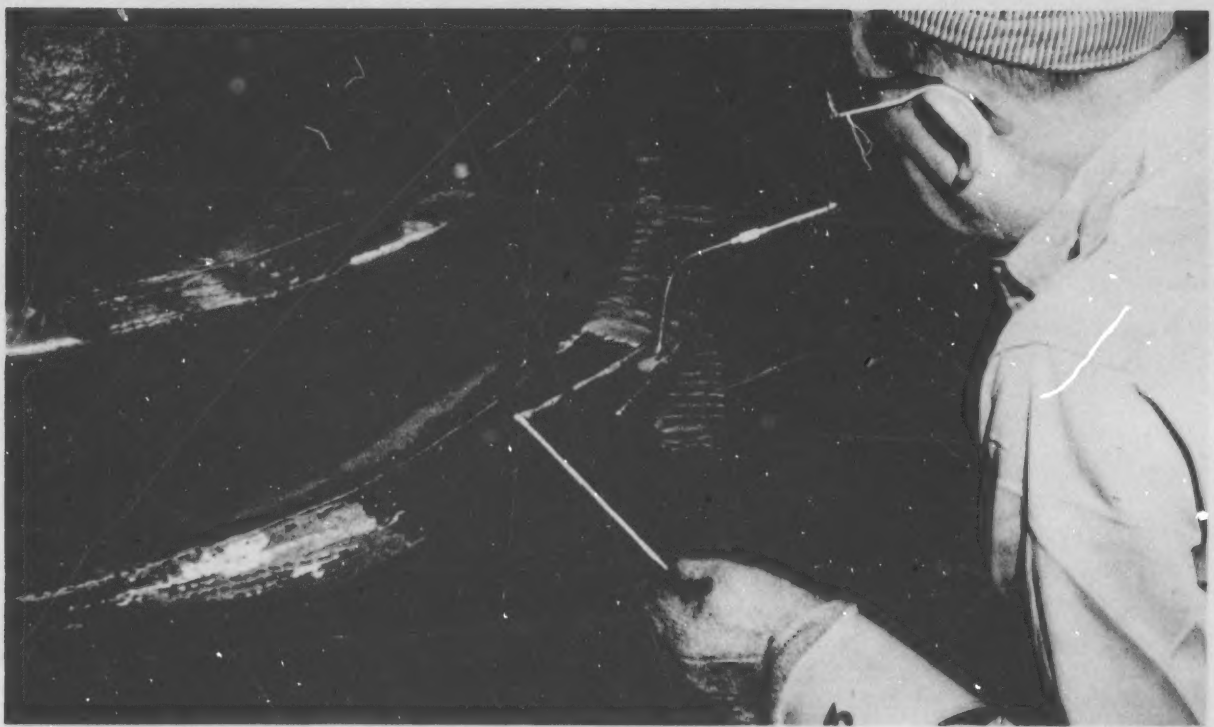

Fig. 87 — Surfacing Of Metal Parts

INTRODUCTION

Surfacing is the depositing of metal on tools and machine parts to increase their sizes, wear life, or other properties.

Examples of surfacing are the building up of worn shafts and gear teeth, hardening of cutting tools (Fig. 87), or replacing metal which has corroded away.

There are two major types of surfacing:

- **Hard surfacing**
- **Metallizing**

HARD SURFACING is a process which gives a hard, tough overlay to resist corrosion, abrasion, and impact loads. (It is sometimes called "hard-facing.")

METALLIZING is a spray coating process in which fine particles of metal are deposited on surfaces where metal has worn away or where contours must be built up.

Let's look at each of the two surfacing techniques — first, *hard surfacing*.

HARD SURFACING

Hard surfacing is much like fusion welding: a special rod, wire, or electrode is mixed with the base metal by heating and melting it.

For good surfacing, the correct filler metal must be used to meet the service requirements of the pieces.

In general, parts which require surfacing get three types of wear:

- **Abrasion**
- **Impact**
- **Corrosion**

Fig. 88 — Surfacing of Bucket Teeth

ABRASION happens with surfaces that are subjected to continuous grinding, rubbing, or gouging actions. For example, low-stress scratching abrasion or erosion is characterized by soil sliding past a plowshare, high-stress grinding action is typified by stone being crushed between metal faces, and gouging abrasion is exemplified by ripper teeth crushing into bedrock.

IMPACT is the absorption of kinetic energy and its release by elastic action. With impact, metal is lost or deformed as a result of chipping, upsetting, cracking, or crushing forces. In abrasion the wearing forces move parallel to the surface of a component, while impact forces are more or less perpendicular to the absorbing members.

CORROSION is the destruction of a surface from atmospheric contamination, chemicals, and oxidation or scaling at high temperatures.

Unless you understand the service condition of the parts to be repaired, it is impossible to select the correct wear-resistant material. Thus surfacing a metal for corrosion wear may not be suitable for impact resistance.

In most cases, surfacing requires the use of a single metal product. However, there are instances when the use of two alloys provide the best results. For example, if a part is extremely worn a less expensive material may be used followed by the appropriate surface deposit. The buildup metal may be a carbon steel of sufficient strength to resist deformation and still support the surface. On the other hand, if the part is subject to impact loading or high temperatures, carbon steel will not be adequate for buildup and an alloy build-up material will have to be used.

METALS WHICH CAN BE SURFACED

Metals which can be surfaced are in two groups:

1. Metals whose physical properties are NOT changed nor are likely to crack during surfacing. Includes low-carbon and medium-carbon steels, low-alloy steels, and stainless steels.

2. Metals whose physical properties ARE changed during surfacing. These metals have usually been hardened and any exposure to heat may undo their heat treatment and produce cracks. Includes high-carbon steels, cast irons, and other alloy steels.

Metals in Group 1 can be surfaced without any particular precautions since no harmful cracking will result.

With metals in Group 2, special care must be taken to reduce the sudden shock of localized heat. This is done by reducing the hardness by annealing or through gradual and uniform preheating and post cooling. Preheating from 300° to 500°F (149 to 260°C) will usually prevent weld hardening in medium and high-carbon steels. High-carbon alloy steels and wear-resistance alloy steels require preheating to the same temperature. After surfacing is completed, reheating to a temperature of 800° to 1300°F (427 to 705°C) and slow cooling should follow.

SURFACING MATERIALS

There are many different types of surfacing materials. Most of them have a base of iron, nickel, copper, or cobalt. Auxiliary elements may be carbon, chromium, molybdenum, tungsten, silicon, manganese, nitrogen, vanadium, and titanium.

The alloying elements form hard carbides which contribute to the matrix properties of the surfacing metals. Thus a high percentage of tungsten or chromium with a high carbon content will form high carbide crystals that are harder than quartz. Materials having a high chromium content provide excellent resistance to oxidation and scaling. Nickel, cobalt, and chromium are particularly effective for corrosion resistance.

The matrix of surfacing metals is either martensitic, pearlitic, or austenitic. Martensite *is* the hardest and strongest. Pearlite is moderately tough and hard. Austenite is soft, strong, tough and has good impact qualities. (For details, see Part 7.)

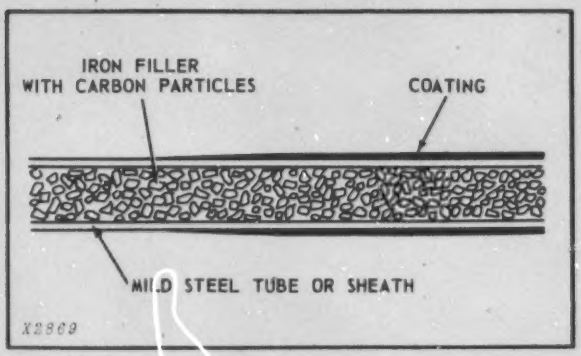

Fig. 89 — Surfacing Electrode

Surfacing metals are available as rods for oxy-acetylene welding, electrodes for shielded metal-arc welding, and hard wire for automatic welding. See Fig. 89. Some surfacing materials come in tubular rods which contain a mixture of powder metal, powder ferralloys and fluxing ingredients. The same material is available in powder form for surfacing with the carbon-arc and the oxy-acetylene powder injector torch.

Although many surfacing materials are designated by manufacturers' trade names, some also carry AWS-ASTM codes.

AWS-ASTM has classified surfacing materials into the following types: high speed steel (Fe5), austenitic manganese steel (FeMn), austenitic high chromium iron (FeCr), cobalt-base metals (CoCr-A and CoCr-C) copper-base alloy metals (CuZn, CuSi, and CuAl), and nickel chromium-boron metal (NiCr).

The coding system identifies the important elements of the surfacing material. The prefix R designates a welding rod and the prefix E an electrode. Suffixes are sometimes used to identify a classification within a basic group. Certain materials also carry a further subdivision in the form of digits after the suffix.

SURFACING WITH OXY-ACETYLENE

The oxy-acetylene surfacing process is very useful in depositing overlays on small parts such as engine valves, plowshares, tools, and other parts.

With the oxy-acetylene flame, tiny areas can be surfaced and thin layers applied smoothly. Preheating and slow cooling are readily controlled, minimizing cracking even with brittle surfacing materials. The prime limitation of the oxy-acetylene technique is its low depositing speed.

Metals for surfacing with oxy-acetylene generally consist of low-melting, high-carbon filler rods such as high chromium or Cr-Co-W alloy. As a rule, a slightly reducing flame is recommended as this will add carbon to the deposit.

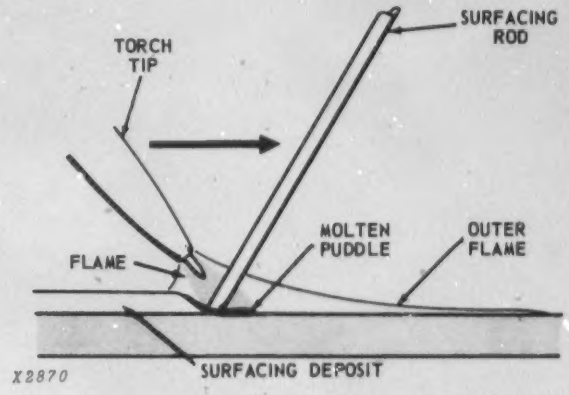

Fig. 90 — Surfacing With Oxy-Acetylene Torch And Surfacing Rod (Backhand Technique Shown)

The surfacing operation is started by preheating the surface to produce a "sweating" condition. During the preheating cycle, the tip of the surfacing rod is held on the fringe of the flame. The rod is then moved into the center of the flame and melted (Fig. 90). The actual depositing of the filler rod is done with a regular welding technique using a slightly weaving motion.

SURFACING WITH ARC

Surfacing with the shielded metal arc is more widely used because of its fast deposition rate. It also has wide application where large areas have to be surfaced or for heavy parts that normally would require excessive time to heat with the oxy-acetylene flame. This method is especially suitable for depositing overlays on manganese steel and other steel alloys where heat buildup must be restricted.

Either AC or DC current produces satisfactory welds. The electrodes may be coated solid wires or hollow tubes containing alloy powder and flux.

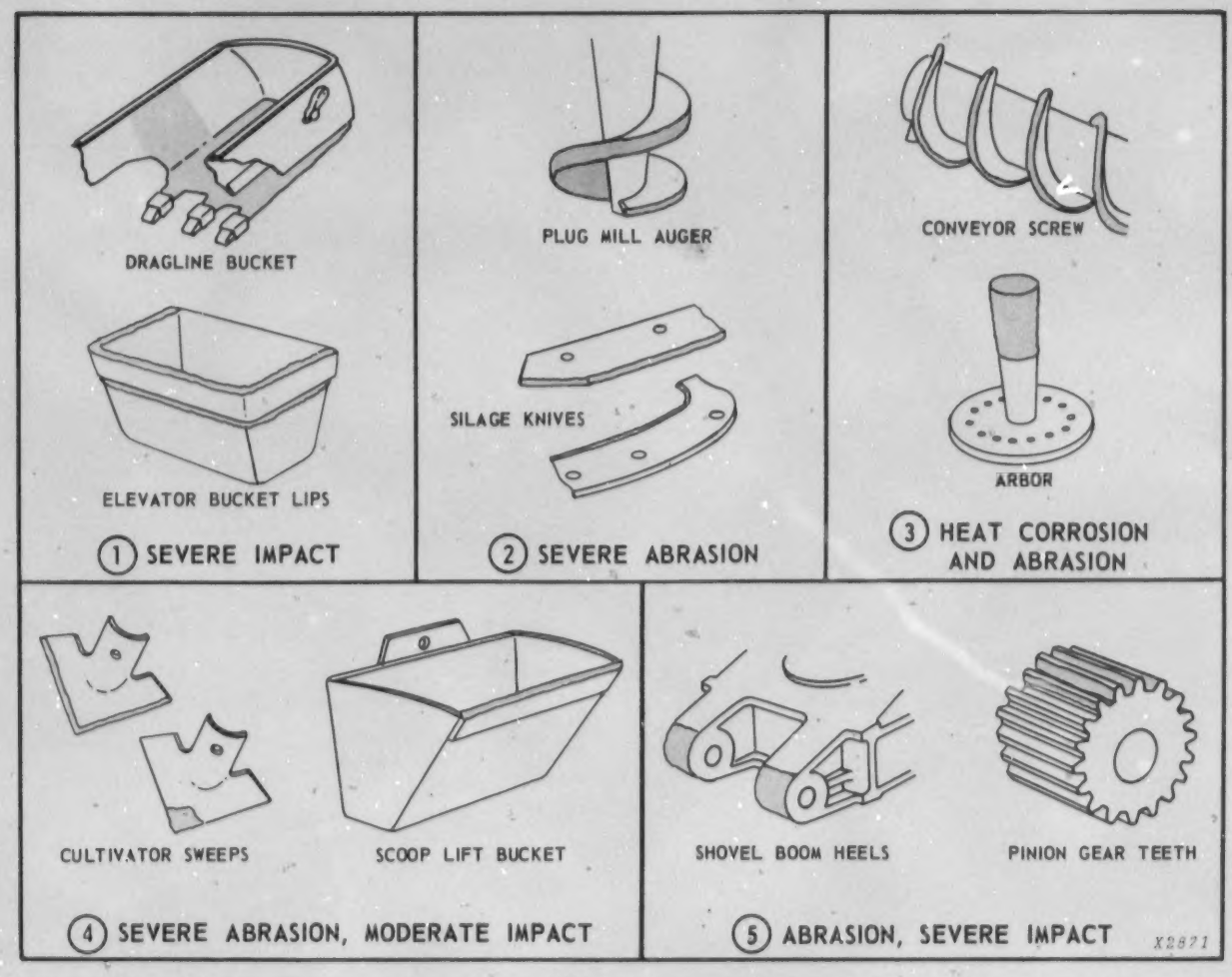

Fig. 91 — Typical Parts Which Require Surfacing

Types of Surfacing Electrodes

Surfacing electrodes are normally classified in five ways:

1. Resistance to severe impact.

2. Resistance to very severe abrasion.

3. Resistance to corrosion and abrasion at high temperatures.

4. Resistance to severe abrasion with moderate impact.

5. Resistance to abrasion with moderate to heavy impact.

Fig. 91 shows typical parts which require surfacing in each of the five groups.

1. **Resistance to severe impact.** These electrodes are intended for repair and buildup of manganese steel, of which most impact resistance parts are made. The electrodes are either solid drawn, that is, they contain all alloying elements in the wire itself, or composite in which all of the alloying elements are in the flux coating.

Deposits of these electrodes are not hard but are very tough. They are often referred to as self-hardening because the deposited surface hardens as it is pounded. While the outside surface is hard, the material underneath remains soft.

Typical equipment requiring impact protection includes: crusher parts, bucket fronts, hammermills, and rolling mill parts, jaws and teeth on dredges, ditchers and power shovels, and other similar heavy industrial and construction equipment. See Fig. 91, No. 1.

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Stainless steel electrodes are often used for surfacing parts that must resist impact forces without cracking. These electrodes offer the least resistance to abrasion in the "as deposited" condition, however, they will work harden. Stainless steel and low hydrogen electrodes are frequently used as base layers for other surfacing electrodes.

2. **Resistance to very severe abrasion.** Electrodes in this group are of the tungsten carbide and chromium carbide types. These electrodes deposit a very hard abrasive-resistant material. They are not suitable for impact wear, since the material they deposit chips and cracks when subjected to shock.

Tungsten electrodes have tiny crystals of tungsten carbide embedded in the steel alloy. When applied on a surface, the steel wears away leaving tooth-like particles of tungsten carbide exposed. Since tungsten carbide is very hard, the exposed particles make the edge of the part self-sharpening. The property is particularly desirable for earth digging equipment, scraping tools, plowshares, rotary digger blades, cultivator sweeps, and similar machinery. See Fig. 91, No. 2.

Still another type of tungsten carbide electrode deposits fine particles of tungsten carbide that are so close that they form a smooth cutting edge. These electrodes are useful in repairing steel cutting edges such as lathe tool bits.

Chromium carbide electrodes are slightly less hard and less abrasion-resistant than the tungsten carbide type but are tougher. Most of them are not affected by heat treatment and are too hard to be machined. In addition to being hard chromium carbide electrodes produce surfaces that provide better protection against corrosion.

3. **Resistance to corrosion and abrasion at high temperatures.** A great deal of wear on metal surfaces occurs at high temperatures, particularly where metal-to-metal contact is involved. In cases where friction is the cause of high operating temperature, special cobalt base alloy electrodes are used for surfacing. These electrodes are capable of withstanding temperatures of 1200°F (650°C) and higher. Cobalt alloy electrodes are excellent for surfacing valves and valve seat facings, chain-saw guide bars, pump shafts, rocker arms, arbors, and conveyor screws. See Fig. 91, No. 3.

Nickel-base alloys also are effective for surfacing metals that are subjected to corrosion and oxidation at high temperatures. For surfacing corrosion-resistant parts which are not used at elevated temperatures, copper-base alloys are sometimes recommended. Copper-base alloy filler metals have wide application in surfacing areas that come in contact with corrosion generating materials such as acids mild alkalies and salt water.

4. **Resistance to severe abrasion with moderate impact.** Industrial, transportation and construction equipment is frequently subject to a combination of wear factors-abrasion and impact. Alloys used for this are carbon-chromium types ranking in hardness from 54 to 65 Rockwell C. In abrasion resistance they are second only to the tungsten carbide alloys. These carbon-chromium alloys lay down a smooth-surfaced deposit that is excellent for moving, cutting, or handling of loose sliding materials such as earth, sand, gravel or cement. See Fig. 91, No. 4.

5. **Resistance to abrasion with moderate to heavy impact.** Many industrial machines such as cable tools, mud pumps, bucket fronts, and churn drills require surfacing alloys that are resistant to abrasion as well as to moderate or heavy impact. These alloys have an iron base and can be heat treated and sharpened to a knife edge. See Fig. 91, No. 5.

How to Surface With An Arc

1. Thoroughly clean metal to be surfaced. Remove all rusts, scale, paint, etc.

2. Set the power supply for only enough amperage to maintain an arc. *This is important to minimize dilution of the deposit by the base metal.*

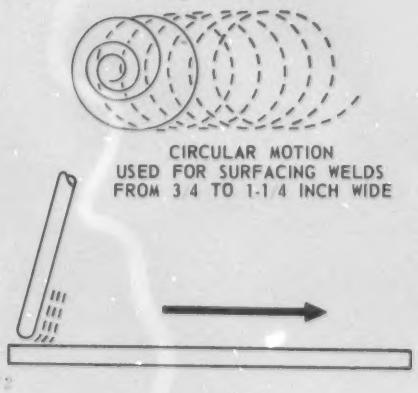

Fig. 92 — Surfacing With An Arc Welding Electrode

3. Place the work in a *flat* position for best results (Fig. 92).

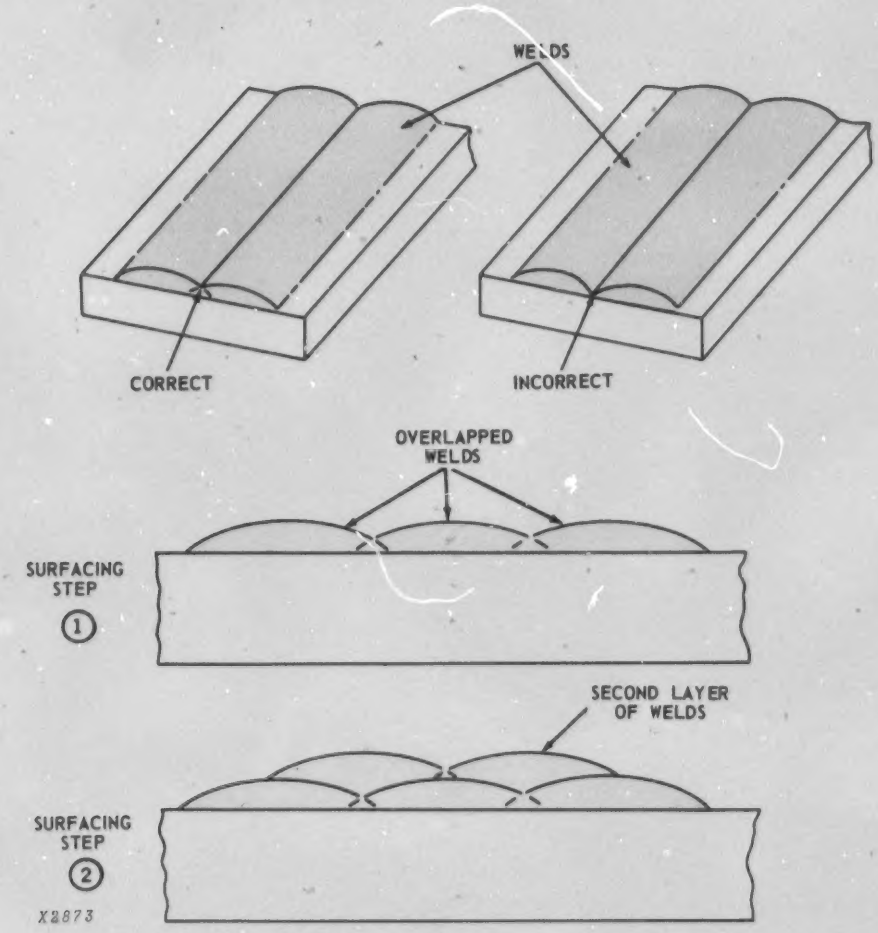

Fig. 93 — Proper Way To Overlap Surfacing Beads

4. Use a medium *long* arc and move with a straight or weaving motion — circular motion for wider surfacing welds as shown in Fig. 93.

5. If several layers are to be deposited, remove all slag before extra layers are made.

6. Overlap welds as shown in Fig. 93. Carefully manipulate the torch as necessary for good complete fusion into the adjoining welds. This can be done by holding the electrode a moment over the deposited weld to allow the heat to build up in the adjoining welds. This will also prevent undercutting.

7. Use a whipping action when surfacing an area along a thin edge. Hold the arc over the heavy portion and then whip it out to the thin edge. In this way a shallow deposit is made before the heat builds up enough in the base metal to burn through.

METALLIZING

Metallizing is a process of depositing fine semi-molten particles or metal powder onto the surface of a metal to form an adherent coating. It is sometimes referred to as "metal spraying."

The powder or metal particles are impelled through an intense heat and are impinged on the surface where they form thin layers of metallic lamellates. The powder or wire rod is fed into an oxygen-fuel gas flame and the small semi-molten droplets are driven onto the surface by a stream of high pressure air. The minute particles strike the surface at estimated speeds of 250 to 500 ft. (76 to 152 m) per second, depending on the gun design.

The metal spray coheres by the mechanical interlocking and fusion of the tiny metallic particles and the bonding of the thin oxide film which forms on the particles while in motion.

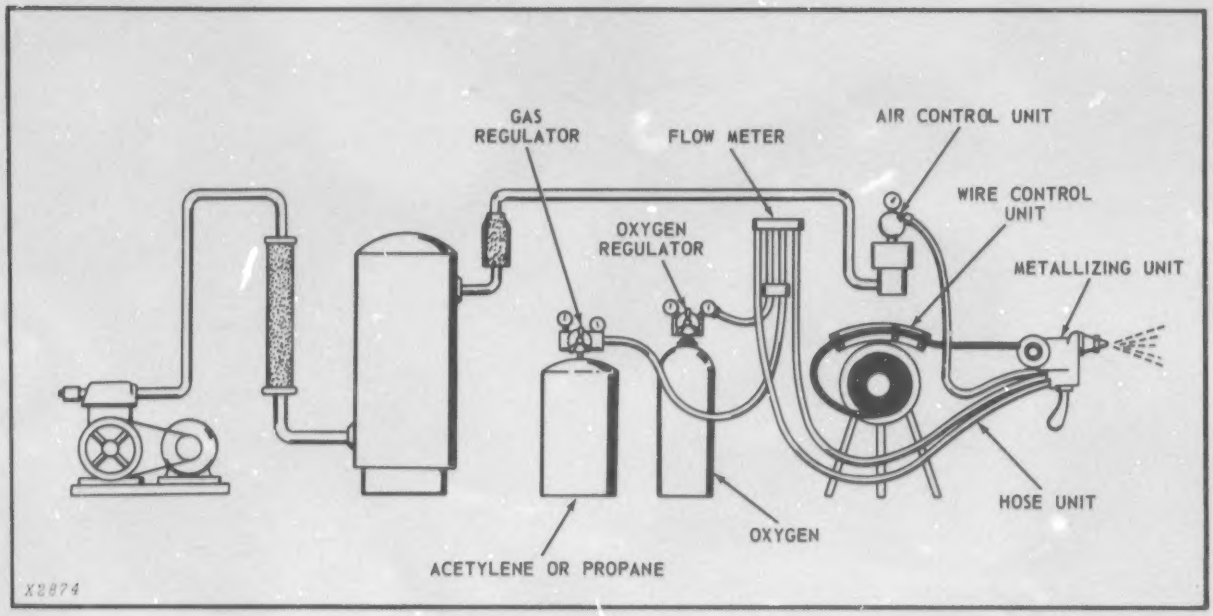

Fig. 94 — A Typical Metallizing Unit

WHERE METALLIZING IS USED

Metallizing has wide use in the machine field where worn surfaces need to be restored to their original sizes but where low tensile strength and porosity are not objectionable. It is very useful for parts where welding or brazing heat is impractical or for applying deposits of dissimilar metals which otherwise are not possible.

The process is unique since there is no limit to the size of the object or structure which can be coated. An extra feature of metallizing is that no preheating or postheating is required.

HOW METALLIZING WORKS

The success of any [illegible] process depends on having a clean surface that has been properly roughened. All traces of oil, dirt, scale, rust, etc., must be removed. The roughing of the surface provides mechanical anchorages for the sprayed metal particles.

Grit blasting is probably the most common method used for surface roughing. Blasting abrasives may be steel grit, hard sand, aluminum oxide, or silicon carbide.

Sometimes after a surface is prepared for spraying a thin layer of molybdenum is sprayed on. This produces a fusion bond which gives greater adherence to the spraying coats. Another method is to run a chasing tool over the area, producing ragged threads.

The sprayed metal coatings are somewhat porous, but in machine elements this is an advantage. The porous coating absorbs oil which provides more complete lubrication. Porosity becomes more critical in applications that are subject to severe attacks of corrosive materials.

Porosity can be partly controlled by the adjustment of gas and air as well as the distance of the gun from the workpiece. However, too much reduction of porosity will usually result in hard, brittle and highly oxidized coatings.

Oxidation normally occurs in the melting flame and during the flight of the metal particles to the surface. As a rule, little oxidation will take place as the metal is melted unless the gas-fuel mixture is oxidizing. The greatest causes of oxidation are overheating of coating, excessive use of oxygen, and spraying too great a distance from the workpiece.

WIRE SPRAY GUNS

Metallizing is done with a special spray gun (Fig. 95) which weighs from 3 to 6 pounds (1.4 to 2.7 kg) and handles 20 gauge to 3/16-inch (0.9 to 4.8 mm) diameter wire. Usually these guns will spray 4 to 12 pounds (1.8 to 5.5 kg) of metal per hour. Larger guns are often mounted on a fixture.

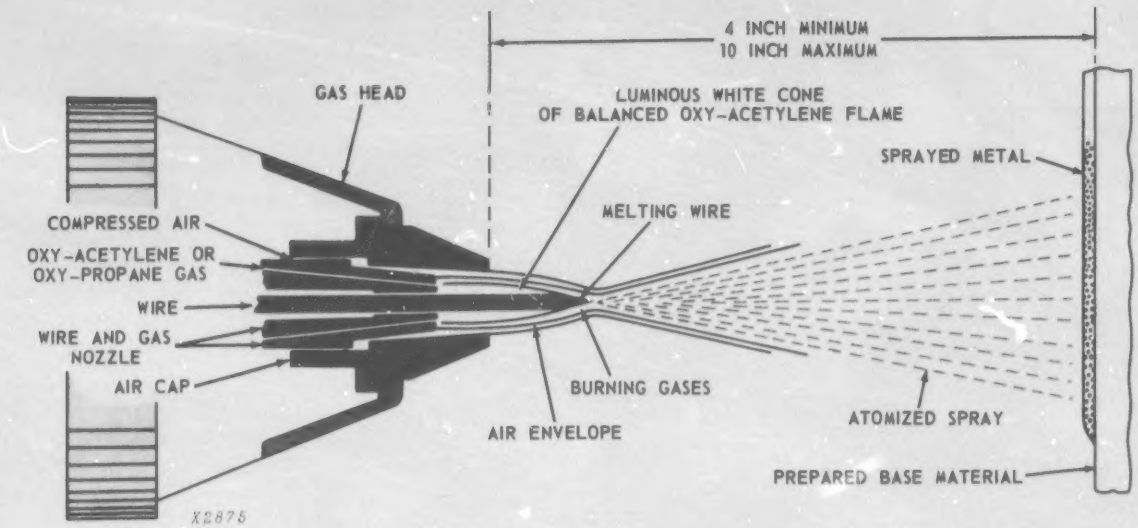

Fig. 95 — Metallizing Spray Gun

The gun has two major parts: the *power unit* and the *gas head*. The power unit feeds the wire into the nozzle of the gun. The gas head controls the flow of oxygen, fuel gas, and the compressed air. The nozzle has a center orifice through which the wire is fed (Fig. 95). Around this orifice are a number of gas jets which provide the flame and high velocity air stream. As the wire comes through the orifice, it is melted and atomized by the flame. The fine molten particles are picked up by the air stream and projected against the work. The most common gas for the oxy-fuel flame is acetylene which produces a temperature exceeding 5600°F (3095°C), although hydrogen or propane is sometimes used for lower melting metals. A schematic sketch of a complete metallizing unit is shown in Fig. 94.

POWDER-TYPE GUNS

Guns used for spraying metal powder are somewhat similar to wire guns except that they do not have a power unit. The powder is carried from a reservoir by compressed air to the gun where it is forced through the central orifice of the gun. The gas flame then melts the tiny particles which are carried to the work by compressed air as in the wire-spray gun.

HOW TO METAL SPRAY

1. Do any metal spraying operation in a well-ventilated area. This is necessary to remove dust particles and fumes which are extremely hazardous to health. If positive ventilation is not possible, wear a respirator.

2. The wire speed, amount of spray, gas, and oxygen pressure must be regulated per recommendations for the equipment used and the type of metallizing. As a general rule, air pressure is set for 60 psi (414 kPa). The use of a flowmeter will insure more accurate control of the gases. A slight increase in air pressure provides a finer coating, while a decrease of air pressure produces a coarser coating.

3. The tip of the melting wire should project beyond the end of the air cap. This length depends to a large extent on the material being used. A recommended practice is to speed up the wire until chunks are ejected. Then reduce the wire feed until the ejection of chunks stops.

4. Keep each coating as light as possible — about 0.003 to 0.005 inch (0.08 to 0.13 mm) in thickness. Too heavy a coat will produce an irregular and stratified surface. The actual movement of the gun is very similar to paint spraying. Keep the nozzle 4 to 10 inches (102 to 254 mm) away from the surface and move with a uniform motion. If the gun is held too close to the work, minute cracks will form in the coating. Too great a distance will produce a soft spongy deposit. The rate of gun travel is also important. When the travel is too rapid, the coating develops a high oxide content.

5. When spraying a flat surface, move the gun back and forth to allow a full uniform deposit. Spraying should begin beyond the edge of the area to be covered and continued beyond the end of the area. After the first layer, the work or gun is often rotated 90 degrees. This technique is repeated for each subsequent coating until the required thickness is built up. On cylindrical pieces, the work is generally fastened in a lathe with the gun mounted on the traveling carriage.

TORCH SPRAYING

Metal spraying of small objects is simplified by using a spray metal torch. This is a hopper and spray control which fits on any regular oxy-acetylene torch.

Metal powder is simply placed in the hopper, the torch is lighted, and the gun moved over the area to receive an overlay. The powder is pulled into the oxy-acetylene stream and becomes fluid when it hits the flame. The surface of the metal must be at "sweat" temperature (liquescent).

TEST YOURSELF

QUESTIONS

1. What is the difference between surfacing and metallizing?

2. Parts which are surfaced are subject to what three basic types of wear?

3. In surfacing metals that are very susceptible to cracking, what can be done to minimize the sudden shock of localized heat?

4. Why is the shielded metal-arc used more than oxy-acetylene in surfacing?

5. When surfacing with an arc, should amperage be as high or as low as possible?

6. When surfacing with an arc, should the arc be medium short or medium long?

7. In metallizing, how do the tiny particles of metal become bonded to a surface?

8. How should a surface be prepared for metallizing? (Two procedures.)

(Answers on page 122.)

DESIGN OF WELDED UNITS / PART 6

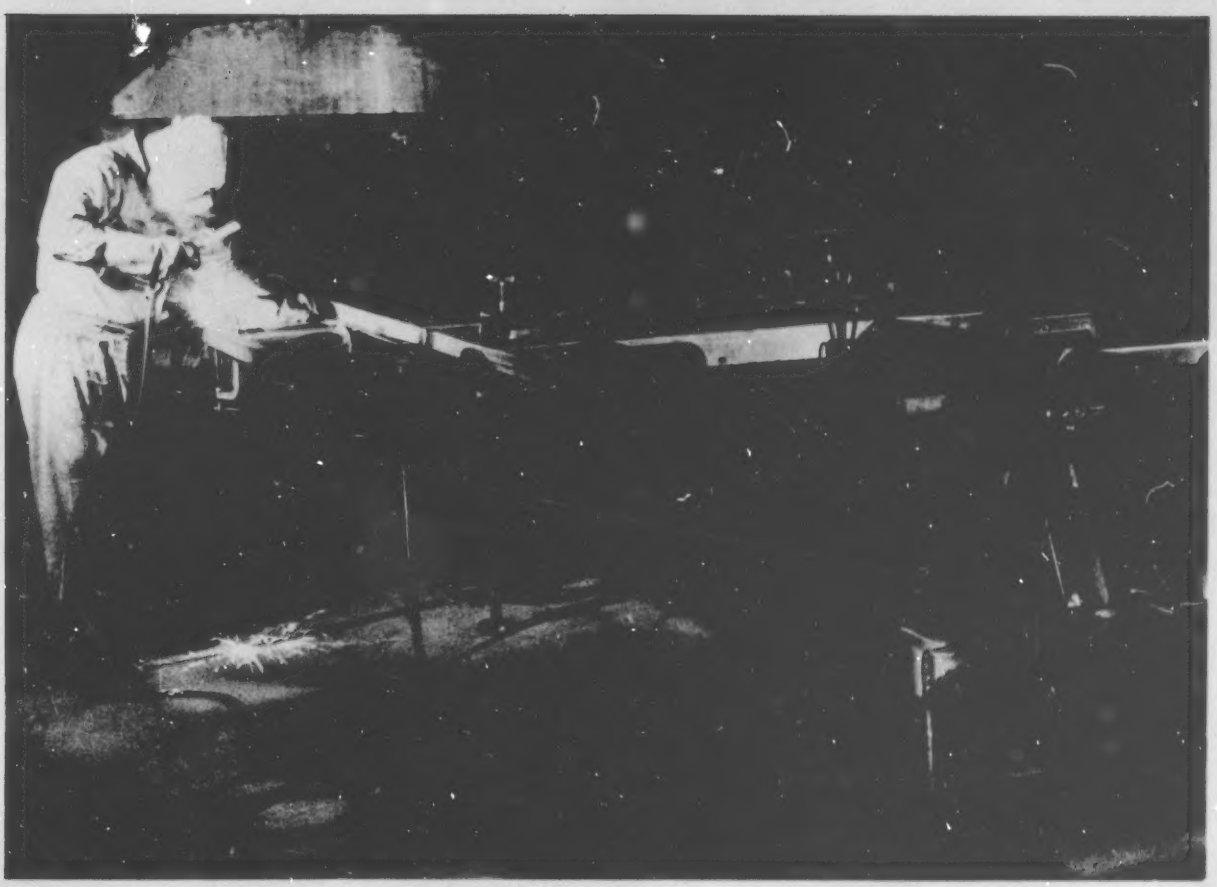

Fig. 96 — Welder At Work On Large Welded Unit

INTRODUCTION

When designing any product, you must resolve whether metal parts are to be welded, cast, or pressed. Too often welding is avoided when it may actually have advantages over other techniques.

For example, it is often easier to build a welded structure by using rolled plates and structural shapes instead of a casting because of greater savings in weight and cost. Similarly, heavy framed units for large machine components will often be easier to construct by welding.

The vital point in any design is to achieve maximum savings in cost but at the same time develop a product that is pleasing in appearance, has sufficient strength, and is safe.

ADVANTAGES OF WELDED CONSTRUCTION

Welding is not the best solution to all design problems. Nevertheless, welding frequently has advantages. These advantages can be summarized as follows:

1. Welding is more **flexible** *and has many basic cost savings over casting and press forming operations.*

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However, this is not necessarily true where high-quantity production runs are required and parts are small.

2. Welding is often three or four times **stronger** *than other fabricating processes and consequently can absorb higher loads* **without** *increasing the weight of the material.*

3. A weld is frequently two to three times **stiffer** *than steel castings, yet is* **more ductile.**

4. There is **less tendency** *for a welded product to* **crack** *due to porosity and shrinkage stresses which are often encountered in a steel casting.*

5. **Investment** *in equipment is generally* **less** *for welding than for other manufacturing processes.*

6. Welded structures provide a greater **freedom of design** *and still meet functional requirements.*

7. Welded parts are much more **resistant to shock** *and impact forces than most castings and therefore give more safety.*

WELDING DESIGN FACTORS

Correct joint design is necessary if welded assemblies are to perform their service and safety requirements.

One of the first requisites of joint design is the **function** of the part.

Next, consideration must be given to the kind of loads imposed on the welded section. Thus, an analysis must be made whether the applied **stress** is one of tension, compression, shear, torsion, or bending.

Joint configuration is next determined on the basis of the design that provides the greatest resistance to the applied load. For example, some types of joints are best if the stress comes from one direction while other joints are more suitable for stresses that are of a more complex nature.

The problem of whether a joint is under a **static or dynamic load** is another factor which affects joint design.

Finally the **efficiency** of a joint, that is, its total strength as compared with the actual base metal, is an important factor.

The principal design factors which are to be covered here are joint design, joint location, weld size, and joint strength.

THE BEST DESIGN

To produce a part at the lowest overall cost, you must evaluate the design to make sure that best use is made of the metallurgical and physical properties of the materials. Consider these factors:

1. The design should satisfy the strength and rigidity requirements of the product. Designing beyond these requirements means that more material and labor will be used, adding to the costs.

2. The safety factor for the design should meet all contingencies. Using too large a safety factor again means added material and labor.

3. The appearance of the product should be pleasing but where areas are hidden from view appearance should not be a critical factor. Less expensive materials can sometimes be used where appearance is not important. For example, hot-rolled steel will frequentiy prove as effective as cold-rolled steel.

4. Since more weight means higher costs, analyze the members to see if stiffeners could be employed for rigidity as a means of reducing weight.

5. Wherever possible, use cheaper low-carbon steel — except that a high-grade steel is best where the added strength reduces the cost.

6. Standard sizes and shapes should be specified wherever it is practical.

7. When a hard surface is required, plan for surfacing, heat treating, or plating.

DESIGN OF JOINTS

Joint design is determined by the cost of preparing the joint, the accessibility of the weld, its adaptability for the product, and the type of loading the weld is required to withstand.

The basic joints used in arc welding are:

1. **Butt joints**
2. **Tee joints**
3. **Lap joints**
4. **Corner joints**

Each group has several variations to provide for different needs.

BUTT JOINTS

The SQUARE BUTT JOINT is primarily for materials that are ⅜ inch (9.5 mm) or lighter and require full and complete fusion for optimum strength. See Fig. 97, A. The joint is reasonably strong in static tension but is not recommended when tension due to bending is concentrated at the root of the weld. It should never be used when it is subjected to fatigue or impact loads, especially at low temperatures. The preparation of the joint is relatively simple since it requires only matching the edges of the plates; consequently the cost is low.

The SINGLE V-BUTT JOINT is used on plate ⅜ inch (9.5 mm) or greater in thickness (Fig. 97, B). Preparation is more costly because a special beveling operation is required and more filler material is necessary. The joint is strong in static loading but like "A" it is not particularly suitable when tension due to bending is concentrated at the root of the weld.

The DOUBLE V-BUTT JOINT (C) is best for all load conditions. It is often specified for stock that is heavier than stock used for a single "V". For maximum strength the penetration must be complete on both sides. The cost of preparing the joint is higher than the single "V" but less filler material is required. To keep the joint symmetrical and reduce warpage the weld deposit must be alternated, welding first on one side and then the other.

The SINGLE U-BUTT JOINT (D) readily meets all ordinary load conditions and is used for work requiring high quality. It has greatest applications for joining plates ½ to ¾ inch (12.7 to 19 mm).

The DOUBLE U-BUTT JOINT (E) is suitable for plate ¾ inch (19 mm) or heavier where welding can readily be accomplished on both sides. Although the preparation cost is higher than the single U-butt joint, less weld metal is needed. The joint meets all regular loading conditions.

TEE JOINTS

The SQUARE TEE JOINT (Fig. 98, A on next page) requires a fillet weld which can be made on one or both sides. It can be used for light to fairly thick materials where loads subject the weld to longitudinal shear. Since its stress distribution is not uniform, care must be taken in specifying this joint where severe impact or heavy transverse loads are encountered. For maximum strength, considerable weld metal is required.

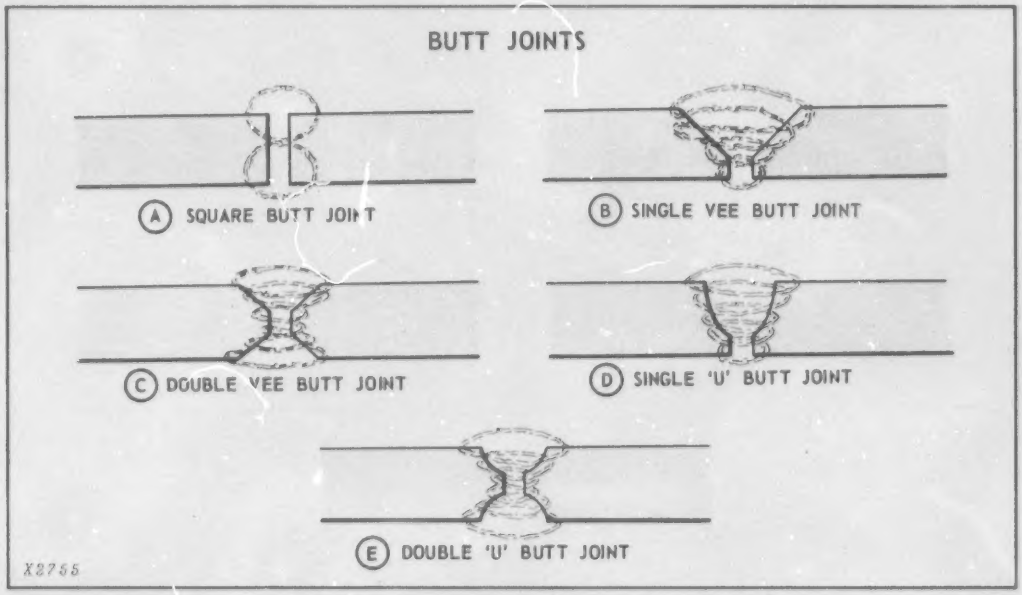

Fig. 97 — Types Of Butt Joints

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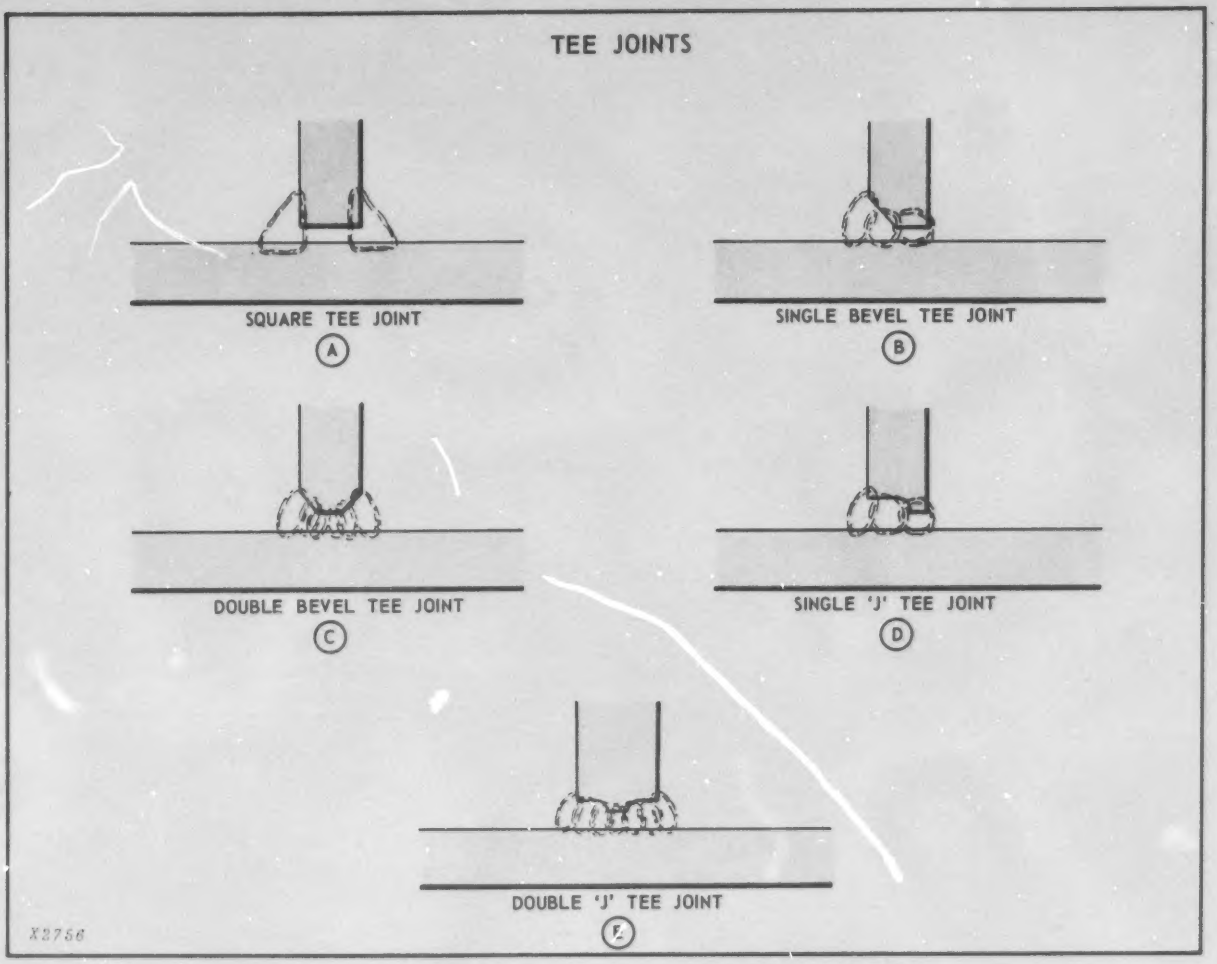

Fig. 98 — Types Of Tee Joints

The SINGLE BEVEL TEE JOINT (Fig. 98, B) will withstand more severe loadings than the square tee joint due to better distribution of stresses. It is generally confined to plates ½ inch (12.7 mm) or less in thickness where welding can be done from one side only.

The DOUBLE BEVEL TEE JOINT (C) is used where heavy loads are applied in both longitudinal and transverse shear and where welding can be done on both sides.

The SINGLE J TEE JOINT (D) is used on plates one inch or more in thickness where welding is limited to one side. It is especially suitable for severe loads.

The DOUBLE J TEE JOINT (E) is suitable in heavy plates 1½ inch (38 mm) or more thick where unusually severe loads must be absorbed. Joint location should permit welding on both sides.

LAP JOINTS

The DOUBLE FILLET LAP JOINT (Fig. 99) can withstand more severe loads than the single fillet lap joint. It is one of the more widely-used joints in welding.

CORNER JOINTS

The FLUSH CORNER JOINT (Fig. 100, A) is designed primarily for welding sheet which is 12 gauge and lighter. It is restricted to lighter materials because deep penetration is sometimes difficult and it supports only moderate loads.

The HALF OPEN CORNER JOINT (B) is usually more adaptable for materials heavier than 12 gauge. Penetration is better than in the flush corner joint.

The FULL OPEN CORNER JOINT (C) is used where welding can be done from both sides. Plates

of all thickness can be welded. This joint is strong and capable of carrying heavy loads. It is also recommended for fatigue and impact applications because of good stress distribution.

The EDGE JOINT (D) is suitable for plate ¼ inch or less in thickness and can sustain only light loads.

SELECTING THE PROPER JOINT

The *square groove joint* is the most economical but it is often good only for products which are to be made of light-gauge material.

Whenever metal is beveled, costs are higher. However, there is often no alternative, especially if heavy plates are to be welded. Without proper edge chamfering, complete penetration is impossible. And without good penetration, the resulting weld joint will be weak.

For the greatest economy, select a root opening and groove angle that requires the least amount of filler material.

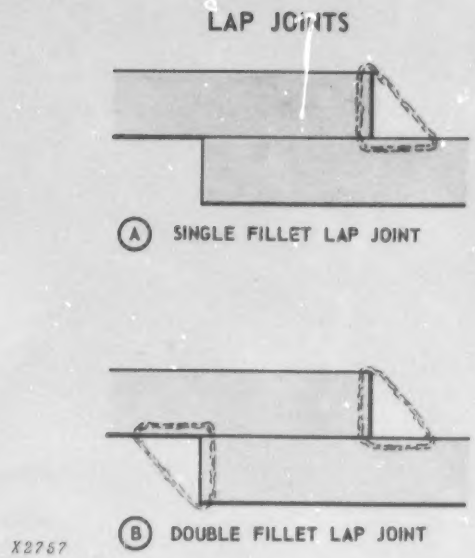

Fig. 99 — Types Of Fillet Lap Joints

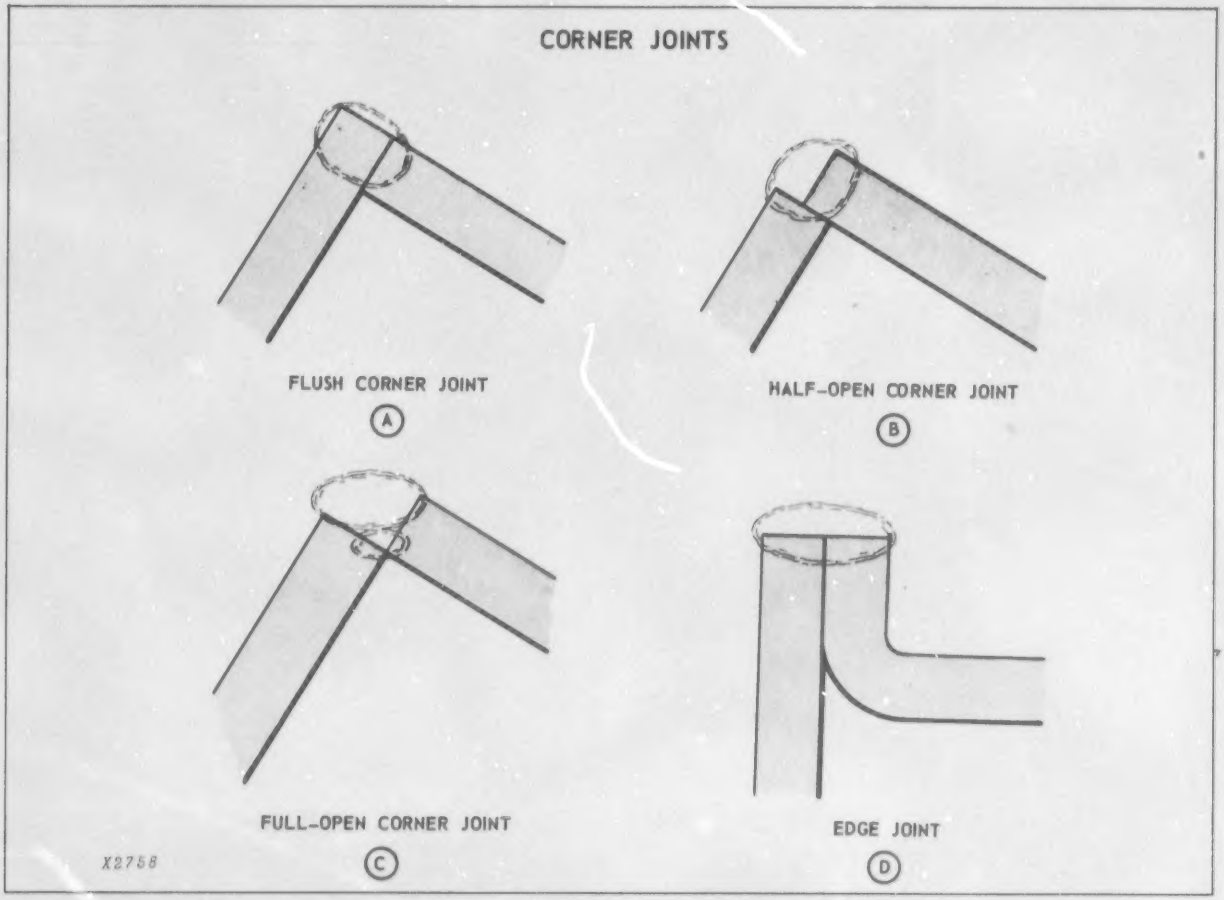

Fig. 100 — Types Of Corner Joints

RECOMMENDED PROPORTIONS FOR VARIOUS JOINTS

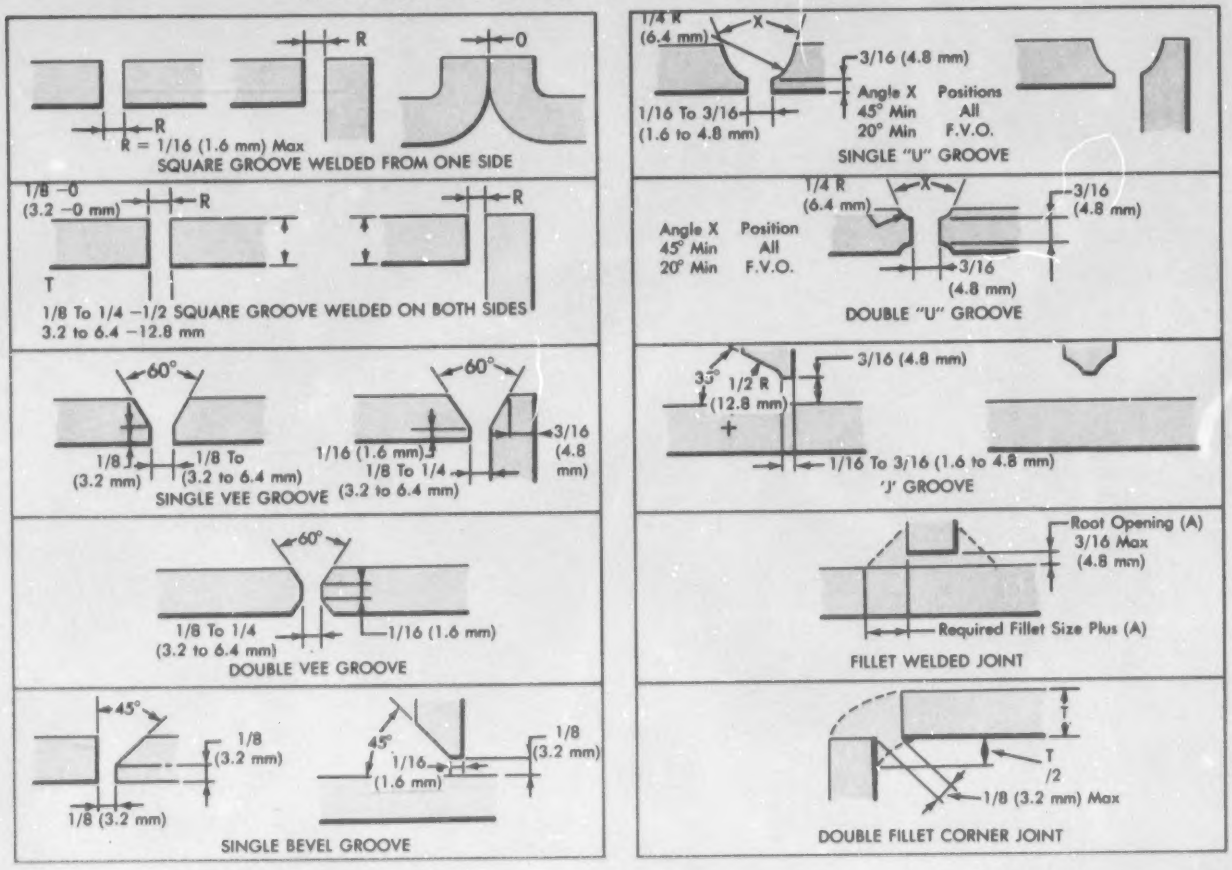

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Fig. 101 — Recommended Proportions For Various Joints

The type of groove angle is frequently governed by the accessibility of the weld. For example, the position of the members may be such that only a single-bevel groove joint is practical. The accessibility of the weld also determines whether a weld is to be made on one side or on both sides.

The required strength of a joint must always be a major factor of joint configuration. Only by actually understanding the type and magnitude of various loadings is it possible to select the joint that will do the job.

Fig. 101 shows the recommended proportions for various joints to produce complete penetration.

LOCATING THE WELDS

Welding is a low-cost method of joining parts but unless careful thought is given to joint design and location of welds, much of the cost saving can be nullified.

There are many factors in proper weld location. Only a few can be illustrated here.

1. The location of the weld in its relationship to the members being joined has a decided effect on the strength of the joint. Normally welds made across the lines of stress are much stronger than welds which are parallel to stress lines. See (A) in Fig. 102. However, transverse welds may cause most stress in the base metal.

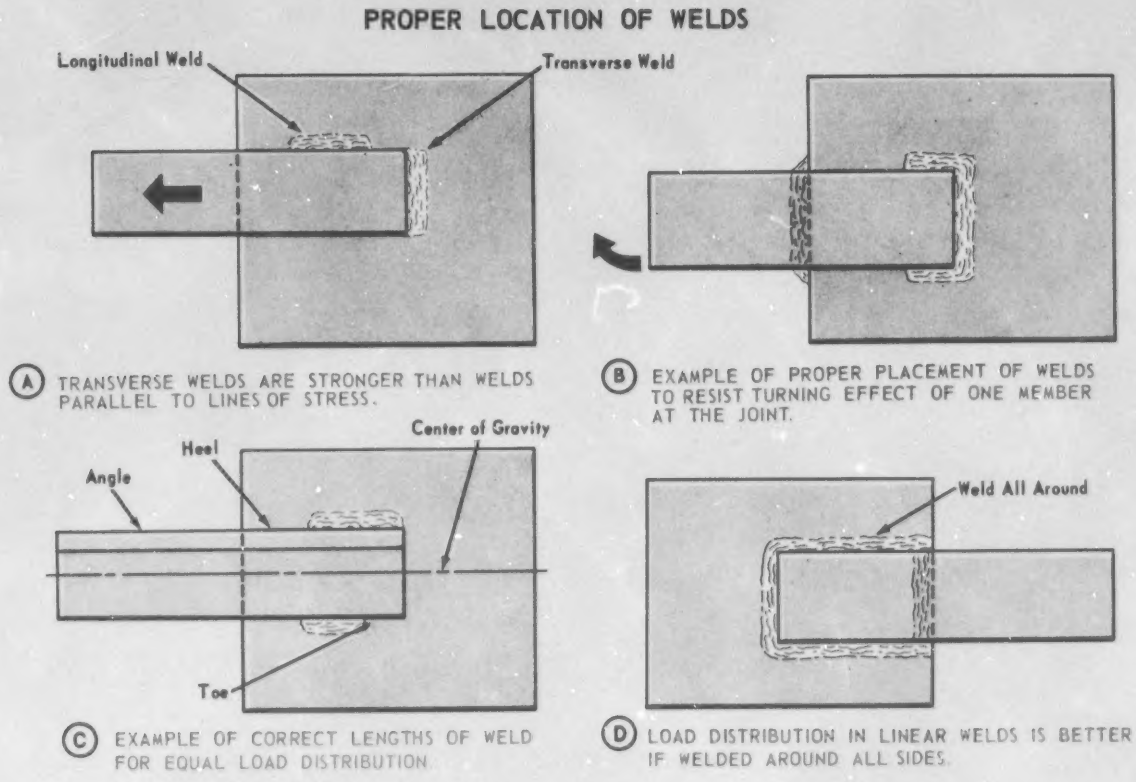
PROPER LOCATION OF WELDS
Longitudinal Weld
Transverse Weld
A TRANSVERSE WELDS ARE STRONGER THAN WELDS PARALLEL TO LINES OF STRESS.
B EXAMPLE OF PROPER PLACEMENT OF WELDS TO RESIST TURNING EFFECT OF ONE MEMBER AT THE JOINT.
Center of Gravity
Heel
Angle
Toe
C EXAMPLE OF CORRECT LENGTHS OF WELD FOR EQUAL LOAD DISTRIBUTION
Weld All Around
D LOAD DISTRIBUTION IN LINEAR WELDS IS BETTER IF WELDED AROUND ALL SIDES.
X2760

Fig. 102 — Proper Location Of Welds

2. A member that is subjected to a movement (turning load) at a joint has greater resistance to turning motions if the welds are spaced apart instead of being close together. See (B) in Fig. 102.

3. When joining shaped sections such as channels, angles, etc., consideration must be given to proper distribution of loads on the welds. Notice in Fig. 102, (C) that the length of the weld at the heel of the angle is greater than at the toe. This eliminates the tendency for the angle to turn and generate highly eccentric loads at the joint.

4. Wherever possible, locate the welded members to avoid bending or shearing actions. Greater strength is achieved if joints are kept symmetrical. Load distribution is more uniform on symmetrical than non-symmetrical joints.

5. To get uniform distribution of loads in linear welds, it is better to weld all around the joint than simply on two sides. See Fig. 102 (D). (The welded piece shown can also be cut at an angle before welding for better strength.)

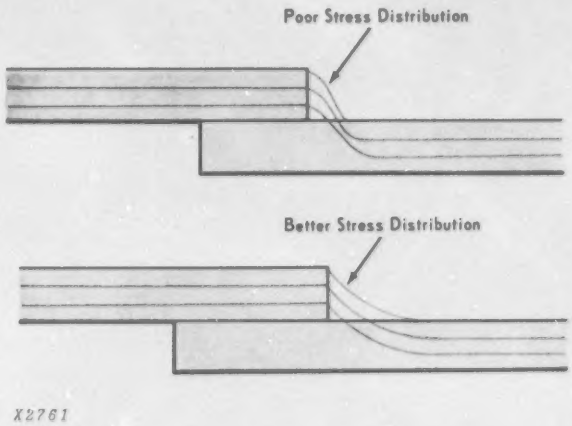

Fig. 103 — Avoid Abrupt Surface Changes In A Joint

6. Abrupt surface changes in a weld joint should be avoided since greater local stresses will be concentrated at the point of surface change. There is a more uniform transfer of stress through a weld if the surface flow is gradual. See Fig. 103.

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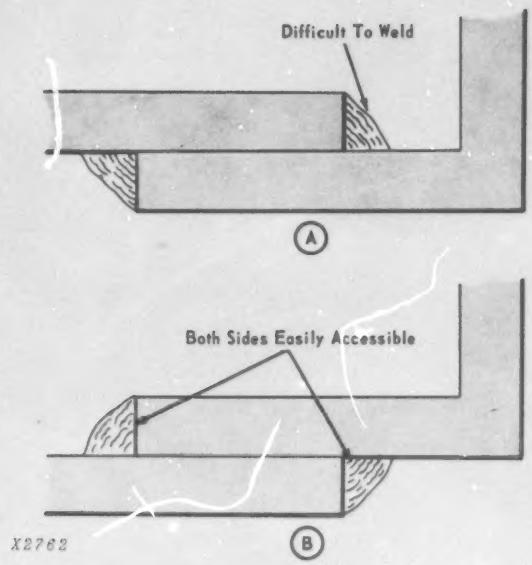

Fig. 104 — Be Sure That Weld Joints Are Easy To Reach

7. Weld joints should be located so they are readily accessible and welding can be done with comparative ease. Notice in Fig. 104 that the weld at (A) is almost impossible to make, whereas the weld at (B) is easily accessible.

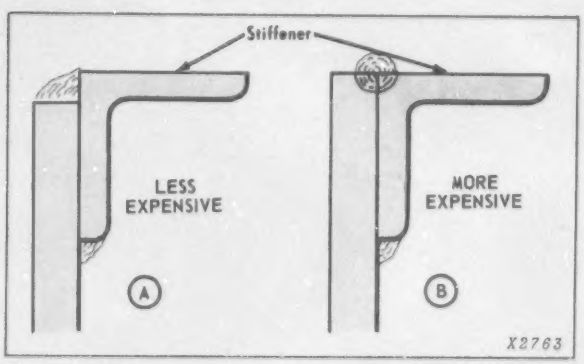

Fig. 105 — Location Of Stiffener For Economy In Welding

8. When an angle is used as a stiffener joined to a plate, use method (A) in Fig. 105 rather than (B). The weld location at (B) becomes more expensive since both beveling and machining the weld is required.

WELD SIZE

Weld size affects cost as well as strength and distortion. It is a common practice to overweld just to be on the "safe side." The volume of metal deposited increases as the square of the length of a leg. In addition to increasing cost, the excess weld metal may generate an uneven load distribution that may result in a concentration of stress and lead to premature failure.

In a **butt weld**, where full strength of the joint is required, the weld must have the same thickness as the connecting plates. As a rule the unit stress and weld size are not calculated because a butt weld has strength equal or greater than the base metal.

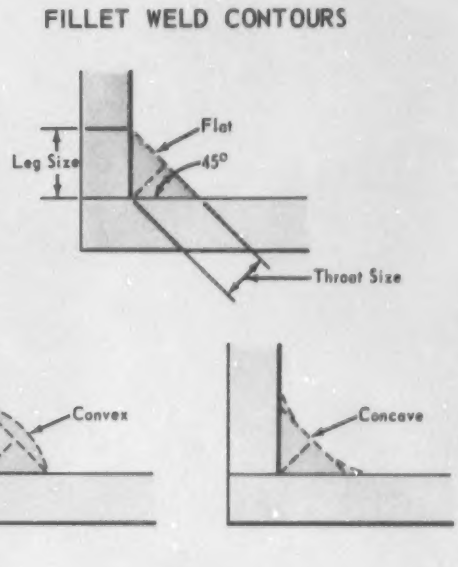

Fig 106 — Types Of Fillet Weld Contours

The strength of a **fillet weld** is based on the effective throat thickness, which is the shortest distance from the root to the face of the weld (Fig. 106). For an equal leg (45°) fillet weld, the throat is .707 (sine of 45°) times the leg size of the weld.

To check the size of fillet welds, it is necessary to make gauges to fit the required contour of the weld deposit. Weld contours may be concave, flat, or convex with equal or unequal legs. The correct fillet size is determined by finding the leg-length of the largest isosceles triangle that can be inscribed within the cross-section of the required weld metal. See Fig. 106.

A *flat* fillet weld has a flat surface and is considered the most ideal weld. A *concave* fillet weld produces a smooth weld flow from one member to another but is often subject to shrinkage cracks. A *convex* fillet weld may result in excess weld metal but has less tendency to crack from shrinking.

To develop the full strength of the plates being connected, a fillet weld must have a *parallel loading* equal to the shear strength of the plate as computed on the basis of a minimum unit shear stress of 15,000 psi (103 425 kPa). It must also have a *transverse loading* equivalent to the tensile stress of the plate as computed at a unit tensile stress of 20,000 psi (137 900 kPa).

In general, this relationship is achieved by **maintaining a fillet width equal to ¾ the plate thickness.** See Fig. 107 and the Table below.

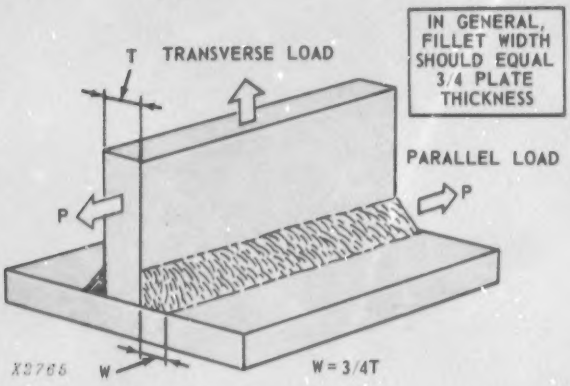

Fig. 107 — A Good Fillet Weld Must Have A Proper Ratio Between Parallel And Transverse Loads

RECOMMENDED FILLET WELD SIZE FOR BEST PLATE STRENGTH (Welded On Both Sides)

Fillet Weld Size (Inch)	(mm)	Plate Thickness (Inch)	(mm)
5/32	(4)	3/16	(4.8)
3/16	(4.8)	¼	(6.4)
¼	(6.4)	5/16	(7.9)
5/16	(7.9)	⅜	(9.5)
⅜	(9.5)	½	(12.7)
½	(12.7)	⅝	(15.9)
⅝	(15.9)	¾	(19)
¾	(19)	1	(25.4)

DEFECTS IN WELDS

When welding, care must be taken to prevent these defects which can weaken the weld:

- **Grain growth**
- **Blowholes**
- **Slag inclusions**
- **Segregation**
- **Porosity**
- **Residual stress**

Let's look at each weld defect in some detail.

GRAIN GROWTH

When welding, a wide temperature differential exists between the molten metal of the actual weld and the edges of the heat-affected zone of the base metal. This temperature may range from a point far above the critical temperature down to an area unaffected by the heat. Thus the grain size can be expected to be large at the molten zone of the weld puddle and to gradually reduce in size until recrystallization is reached.

Effective control of preheating and postheating will often minimize the formation of coarse grain structure. Where heavy welds require successive passes, use the heat of each succeeding pass to refine the grain of the previous pass. This can be done only if the metal is allowed to cool below the lower critical temperature between each pass.

High carbon and alloy steels are particularly vulnerable to coarse grain growth if cooled rapidly. The rapid cooling develops a martensitic condition, leaving a hard and brittle weld.

BLOWHOLES

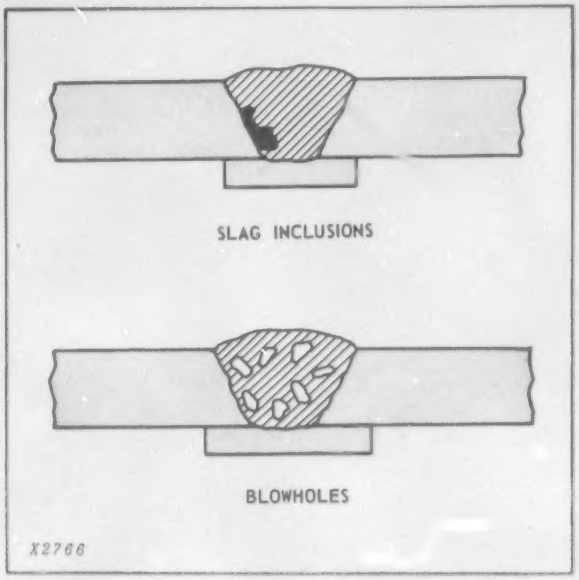

Fig. 108 — Welding Defects

FOS — 52 Litho In U.S.A.

Blowholes are cavities caused by gas trapped during the solidification of the weld metal (Fig. 108). They usually develop because of improper manipulation of the electrode and failure to maintain the molten pool long enough to float out the entrapped gas, slag, and other foreign matter. When gas and other foreign material become trapped in the grains of the solid metal, small holes are left in the weld after the metal cools.

To avoid blowholes, keep the molten pool at a uniform temperature throughout the welding operation. This can be done by using a constant welding speed so the metal solidifies evenly. Blowholes are most likely when stopping and starting the weld along the seam.

SLAG INCLUSIONS

Inclusions are impurities or foreign substances which are forced in a molten puddle during the welding process (Fig. 108). Any inclusion tends to weaken a weld because it has the same effects as a crack.

A typical example of an inclusion is slag which normally forms over a deposited weld. If the electrode is not manipulated correctly the force of the arc causes some of the slag particles to be blown into the molten pool and become lodged in the metal. Inclusions are more likely to occur in overhead welding since the tendency is not to keep the pool molten too long to prevent it from dripping off the seam.

SEGREGATION

In segregation, some regions of the metal are enriched with an alloy ingredient while surrounding areas are actually impoverished. For example, when metal begins to solidify, tiny crystals form along grain boundaries. These crystals tend to exclude alloying elements. As other crystals form they become progressively richer in alloying elements, leaving other regions without the benefits of the alloying ingredients. Segregation can be remedied by proper heat treating or slow cooling.

POROSITY

Porosity is the formation of tiny holes generated by atmospheric contamination. Some metals have a high affinity for oxygen and nitrogen when in a molten state. Unless a good protective shield is provided over the molten metal, gas will enter the metal and weaken it.

RESIDUAL STRESSES

Any rapid heating and cooling of weld metal will produce thermal stresses which may weaken the welded joint. Heating causes rapid expansion of the metal around the weld, while rapid cooling results in contraction of metal which creates residual stress.

If large areas of unaffected metal surround the weld area or if the section is rigidly clamped, the solidifying weld metal readily develops internal or locked-up stresses. These stresses are not serious in welding ductile metal because the flow of metal will usually relieve the stresses. However, they may become very serious in metals of great rigidity unless provisions are made to compensate for expansion and contraction.

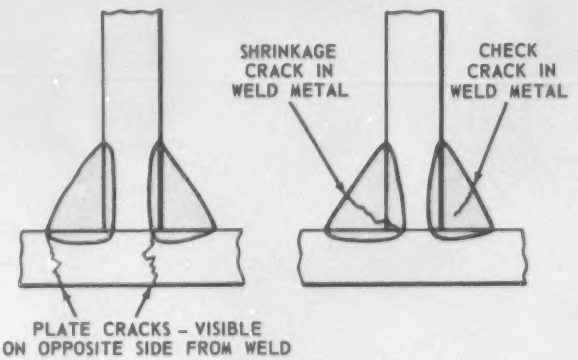

Fig. 109 — Residual Stresses Cause Cracks In The Weld Metal And The Plates

Residual stresses form cracks in the weld metal and in the base metal surrounding the weld (Fig. 109).

Control of Residual Stresses

Control of residual stresses can be achieved by following these steps:

1. Properly Preparing And Assembling Edges

Bevel edges of plates and allow sufficient space between them to prevent the movement of the component parts during welding. Weld the joints held most solidly in a fixture first. Thus a long longitudinal seam is welded before a short transverse seam.

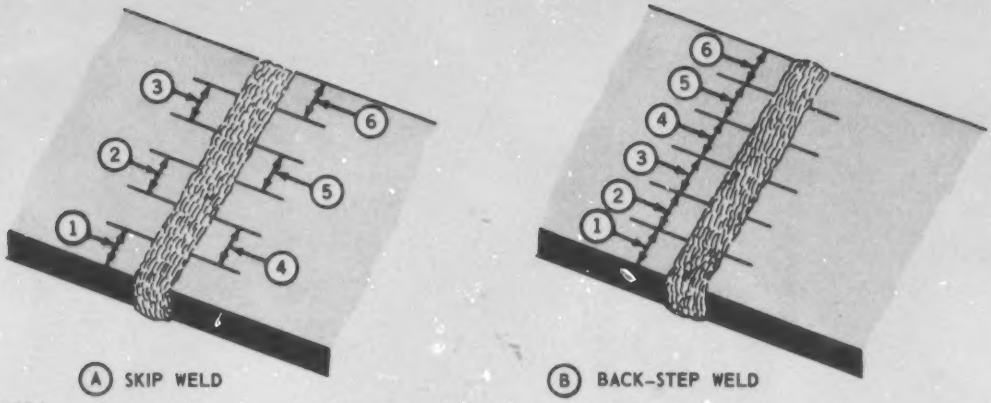

Fig. 110 — How To Control The Heat Input During Welding

2. Controlling the Heat Input

The faster a weld can be made, the less heat is absorbed in the base metal.

A technique often used to reduce heat input is the intermittent or *skip weld* (Fig. 110, A). Instead of making one continuous weld, a short weld is made at the beginning of the joint (1); next a few inches are welded at the center of the seam (2); and then a short length is welded near the end of the joint (3). Finally, the welding is returned to where the first weld ended, and the cycle is repeated as shown in 4, 5, and 6.

In the *back-step* or step-back method, short sections of weld are deposited as shown in Fig. 110, B instead of making one continuous weld.

3. Preheating The Metal

On many pieces, particularly alloy steels and cast iron, expansion and contraction forces can be controlled by preheating the entire structure before the welding is started. To be effective, preheating must be kept uniform throughout the welding operation, and after the weld is completed the piece must be allowed to cool slowly.

4. Peening The Metal As It Cools

To help the metal stretch as it cools, a common practice is to peen it lightly with the round end of a ball peen hammer. However, peening should be done with care because too much hammering will stress the weld or cause it to work-harden and become brittle.

5. Heat Treating The Metal

Heat treating is a common way to relieve stress in metals. The welded component is placed in a furnace capable of uniform heating and temperature control. The metal must be kept in a soaking temperature until it is heated throughout.

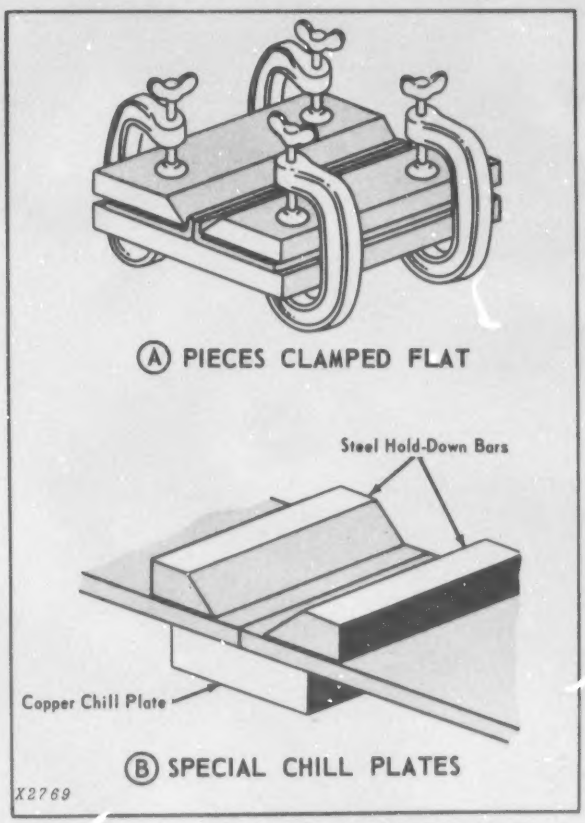

Fig. 111 — Use Of Jigs And Fixtures

Correct temperatures are important to prevent injury to the metal being treated. For example, mild steels require temperatures of 1100 to 1200°F (594 to 650°C), while other alloy steels must be heated to temperatures of 1600°F (872°C) or more.

After the proper soaking period, the heat must be reduced gradually to atmospheric temperature.

6. Using Jigs and Fixtures

The use of jigs and fixtures will help prevent distortion, since holding the metal in a fixed position prevents excessive movements. A jig or a fixture is any device that holds the metal rigidly in position during the welding operation.

Fig. 111 (A) shows a simple way to hold pieces firmly in a flat position. These heavy plates not only prevent distortion but they also serve as *chill blocks* to avoid excessive heat building up in the work.

Special chill plates made of copper or other metal having good conductivity are particularly effective in dissipating heat away from the weld area. See Fig. 111.

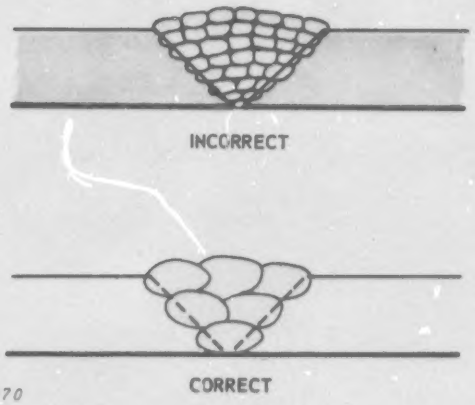

Fig. 112 — Use Fewest Weld Passes To Reduce Distortion

7. Using Fewest Weld Passes

Distortion can be kept to a minimum by using as few passes as possible over the seam. See Fig. 112. Two passes made with large electrodes are often better than three or four with smaller electrodes.

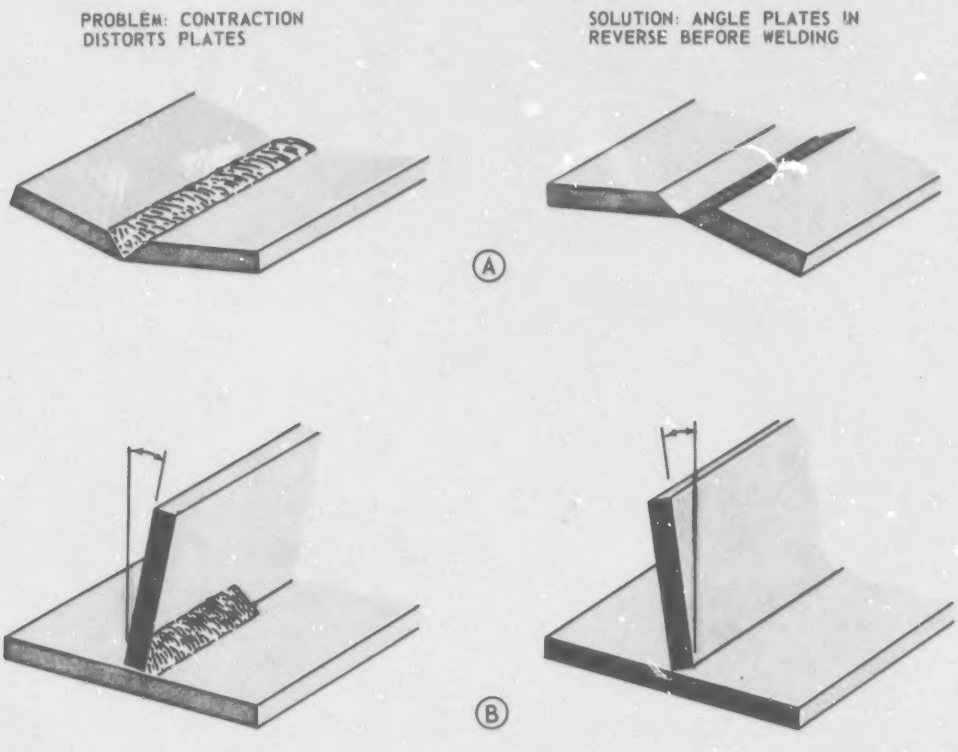

Fig. 113 — Distortion Is Reduced By Proper Positioning Of Parts

8. Allowing For Heat Distortion

When a single V-butt joint is welded, the greater amount of hot metal at the top than at the root of the "V" will cause more contraction across the top of the welded joint. The result is a distortion of the plate as shown in Fig. 113, A.

In a T-joint, the weld along the seam will bend both the upright and flat piece. See Fig. 113, B.

To reduce these distortions, angle the pieces slightly in the *opposite* direction in which contraction is to take place. Upon cooling, the contraction forces will pull the pieces back into position.

OTHER WELDING PROBLEMS

Welding problems related to *wrong welding techniques* — such as undercutting — are covered in earlier sections of this manual.

Review these areas for a supplement to the welding defects covered here.

TEST YOURSELF

QUESTIONS

1. What advantages can a welded construction give over a metal casting or pressed unit? (List three)

2. Draw a simple sketch of these types of joints:
   a. Square butt joint
   b. Double V-butt joint
   c. Square tee joint
   d. Double bevel tee joint
   e. Double fillet lap joint

Using a colored pencil, draw in good welds for each joint.

3. Which is recommended for heavier metal plates, a square butt joint or a V-type butt joint?

4. Which are normally stronger, welds which are parallel or transverse to the stress lines of the joint?

5. When a joint receives turning loads, should the welds be spaced apart or close together?

6. (Select one). In general, fillet welds should be (½ — ⅔ — ¾) the thickness of the metal plate.

7. Match the items on the left below with the correct one on the right.

a. Blowholes	1. Cracks in weld or base metal.
b. Grain growth	2. Coarseness of metal near welds.
c. Slag inclusions	3. Foreign substances in the weld.
d. Residual stresses	4. Gas cavities in the weld.

8. What is *skip welding* and why is it used?

(Answers on page 122.)

PROPERTIES OF METALS / PART 7

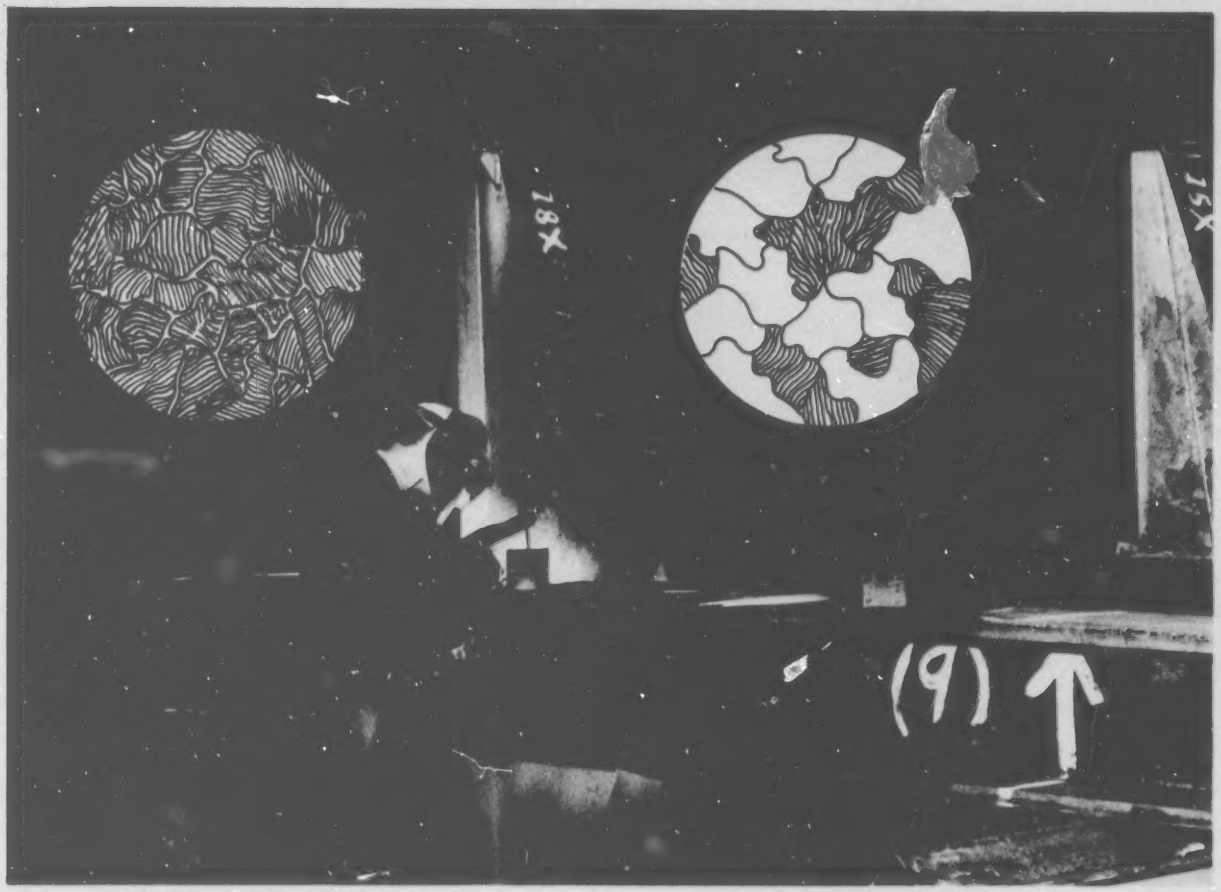

Fig. 114 — Welder At Work On Heavy Steel (Insets — Magnified Views Of Two Carbon Steels)

INTRODUCTION

To weld, you must have a basic knowledge of metals. All of the problems of metal casting are present in fusion welding — expansion, contraction, shrinkage, cracks, hardening, and brittleness.

Welding affects any metal. Sometimes the effects are slight, but they can be harmful if certain rules are not followed.

FERROUS AND NONFERROUS METALS

Metals are divided into two major groups:

- **Ferrous metals**
- **Nonferrous metals**

FERROUS metals *contain iron* and its alloys such as steel (Fig. 115).

NONFERROUS metals are those with *little or no iron*. They include copper, brass, zinc, bronze, lead, and aluminum.

Most welding is done on ferrous metals, but recent developments have made welding possible on most nonferrous metals as well.

MELTING POINTS OF METALS

The melting points of various metals and alloys are vital to good welding. The chart in Fig. 116 (next page) gives this data.

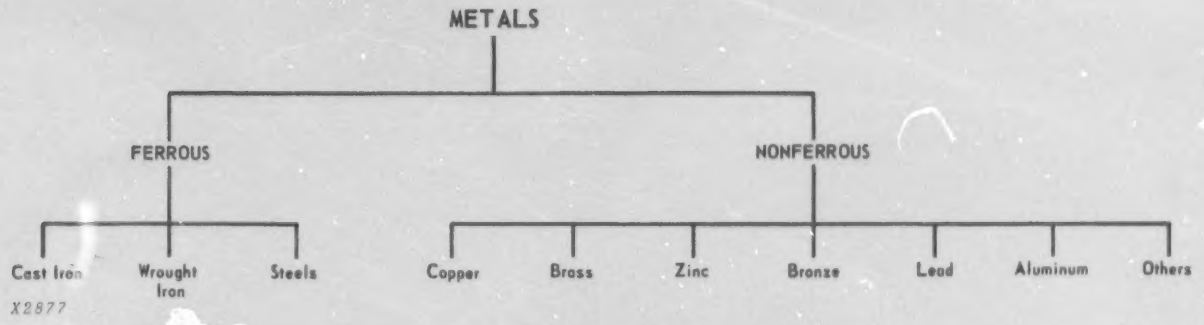

Fig. 115 — Types Of Metals

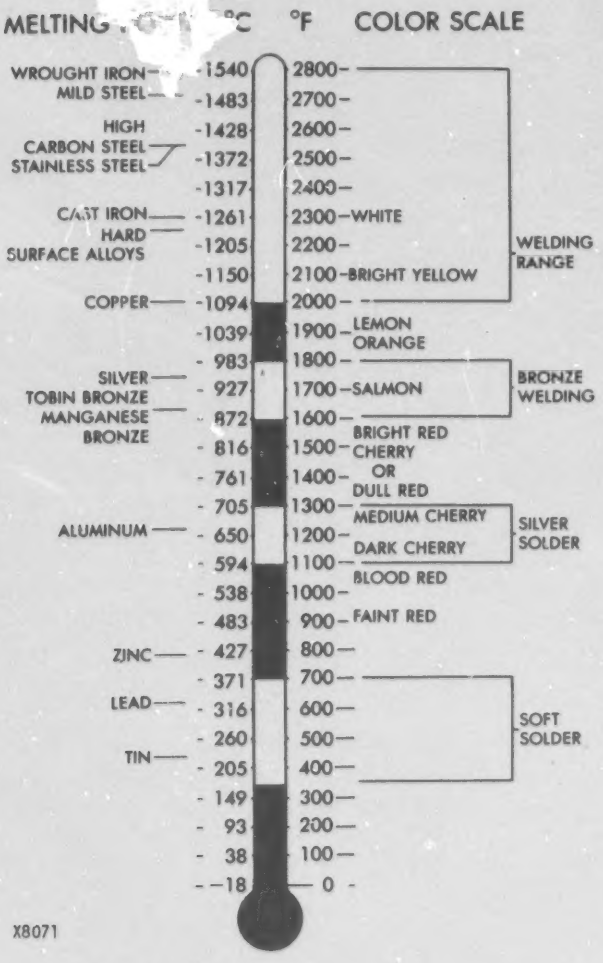

Fig. 116 — Melting Points Of Metals And Alloys

IRON AND STEEL

Iron is produced by reducing iron oxide, commonly called iron ore, to pig iron by means of a blast furnace.

Carbon steel is an alloy of iron and controlled amounts of carbon. **Alloy steel** is a combination of carbon steel and controlled amounts of other desirable metal elements.

The percentage of carbon content determines the type of carbon steel. For example, wrought iron has .003 percent carbon, meaning three thousandths of one percent. Low carbon steel contains less than .30 percent carbon. Medium carbon steel varies between .30 and .45 percent carbon content. High carbon steel contains approximately .45 to .75 percent carbon, and very high carbon steel contains between .75 and 1.50 percent carbon.

Cast iron contains 2¼ to 4 percent carbon. Some is in the noncombined form and is in the form of graphite in gray cast iron.

The carbon generally combines with iron to form iron carbide, a very hard, brittle substance. This action means that *as the carbon content of the steel increases, the hardness also tends to increase.*

Various *heat treatments* are used to enable steel to retain the strength of its higher carbon content, and yet not have the extreme brittleness usually found with high carbon steels. Also, certain other substances such as nickel, chromium, manganese, vanadium, and other alloying metals may be added to steel to improve its physical properties.

A welder must also have an understanding of the *impurities* occasionally found in metals and their effect upon the weldability of the metal.

Two of the harmful impurities sometimes found in steels are phosphorus and sulphur. Their presence in the steel is due to their presence in the ore, or to the method of manufacture. Both of these impurities are detrimental to the welding qualities of steel; therefore during manufacture, extreme care is always taken to keep the impurities at a minimum (.05 percent or less).

Sulphur improves the machining qualities of steel, but it is harmful to its hot-forming properties.

During welding, sulphur or phosphorus tend to form gas in the molten metal, resulting in gas pockets in the welds. Brittleness is also increased because of the sulphites and phosphates formed.

Another impurity is dirt or slag (iron oxide) imbedded in the metal. These impurities may produce blowholes in the weld and reduce the physical properties of the metal.

PHYSICAL PROPERTIES OF METALS

A physical property is a characteristic of a metal which may be observed or measured.

The physical properties of steel are affected by the following:

1. *Carbon content.*
2. *Impurities.*
3. *Addition of various alloying metals.*
4. *Heat treatment.*

Testing machines are being introduced into some welding shops to allow operators to identify metals and to check on the physical properties of welds.

The vital physical properties of steels are:

1. **Tensile strength.**
2. **Ductility.**
3. **Hardness.**
4. **Brittleness.**
5. **Compression strength.**
6. **Elongation.**
7. **Malleability.**
8. **Toughness.**
9. **Grain size.**

Fig. 117 illustrates the types of stresses imposed on metal structures.

Tensile strength is the ability of a metal to resist being pulled apart. This can be measured on a tensile testing machine which puts a stretching load on the metal.

Ductility is the ability of a metal to be stretched. A very ductile metal such as copper or aluminum may be pulled through dies to form wire. The ductility of iron and steel may be measured during a tensile test.

Hardness is the quality which allows a metal to resist penetration. The Rockwell, Brinell, or Scleroscope may be used to test hardness in iron or steel.

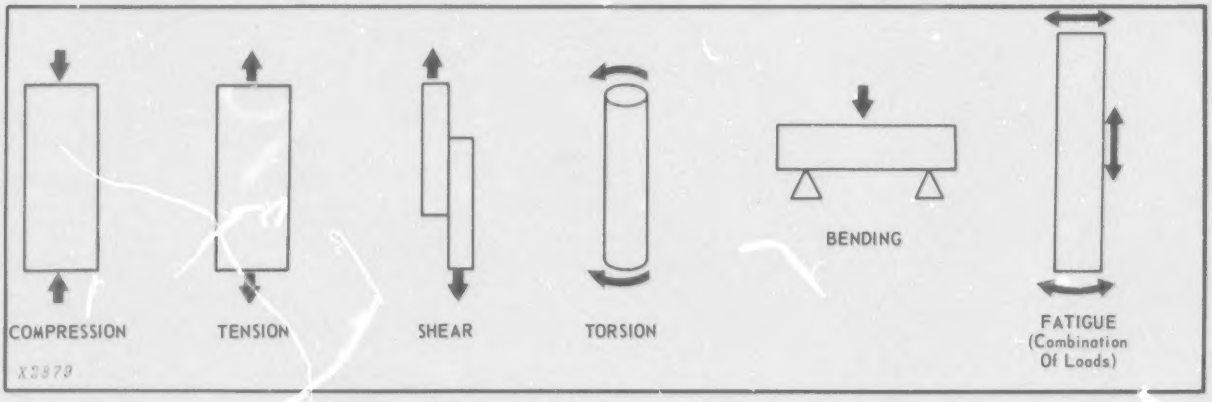

Fig. 117 — Types Of Stresses Or Loads On Metal Structures

Brittleness in a metal means it will fracture easily if bent sharply or struck a sharp blow. Cast iron, especially in thin sections, is very brittle.

Compression strength of a metal is a measure of how much squeezing force it can withstand before it fails. The metal to be tested is mounted in a tensile tester, but instead of pulling on the metal, it is squeezed or compressed.

Elongation is measured by how much a metal will stretch before it breaks. The percent of elongation is measured during a tensile test. Two marks exactly two inches apart are placed on the tensile sample and the distance between the marks is again measured after the sample breaks. The original distance between the marks is compared to the increase in length to determine the percent of elongation. Cast iron is brittle, so its percent of elongation is very low.

Malleability is the tendency of a metal to be hammered into shape. Low carbon steel is malleable, while cast iron is not.

A metal is said to be *tough* if it can withstand repeated bending or twisting.

The examination of the *grain size* of a known metal under a microscope will give a good idea of the brittleness of a metal, its tensile strength, the heat treatment, and its ductility.

Before these properties can be studied in detail, you must have an understanding of the effect of carbon on the properties of steel, and a good knowledge of alloys in general.

ALLOY METALS

An alloy metal is an intimate mixture of two or more metals.

Any ferrous or nonferrous metal may be alloyed to form an alloy metal with new and desirable characteristics.

Steel is an alloy of iron and controlled amounts of carbon. **Alloy steels** are created by adding other metals to plain carbon steel.

Some metals which are alloyed with carbon steel and their qualities are:

Chromium — Increases resistance to corrosion; improves the responsiveness to heat treatment.

Manganese — Increases strength and responsiveness to heat treatment.

Molybdenum — Increases toughness and improves the strength of steel at higher temperatures.

Nickel — Increases strength and toughness; increases impact resistance.

Tungsten — Produces dense, fine grain; helps steel to retain its hardness; helps steel to retain strength under high heat.

Vanadium — Retards grain growth and improves impact resistance.

The *melting point* of a metal is changed somewhat whenever an alloying metal is added.

Note in Fig. 116 the various melting point of steels as compared to cast iron. For example, while cast iron melts at about 2300°F (1261°C), a high carbon steel melts at about 2550°F (1400°C).

Another example of a simple alloy is the combination of lead and tin. The melting temperature of lead is 635°F (335°C), while tin has a melting temperature of 432°F (222°C). However, as the two metals are mixed, any combination of the two results in a lower melting temperature than 635°F (335°C). At a certain proportion of the metals, the lowest melting temperature is reached, which is lower in a simple alloy, than the melting temperature of either of the two pure metals separately.

COOLING CURVES

The temperature of a metal (not an alloy) under atmospheric pressure remains constant during the change from the liquid to the solid state.

As most metals are heated to their melting temperature, a thermometer will show a constant rise in temperature per unit of time, with a constant heat input, until the metal reaches its melting temperature.

However, as the metal *melts*, the temperature will remain *constant* for a length of time. During this time, the molecular structure of the metal absorbs heat energy which is required to change the position of the metal atoms in the structure of the molecule as the metal changes from a solid to a liquid state. After the metal is melted, the temperature will again rise as the metal is heated.

As a metal cools from the liquid state, the temperature drops until the metal solidifies. At this point, the temperature will remain constant while the atoms in the metal molecules change back to the solid state molecular structure. During this time while the atoms are changing position in the molecule, the molecule releases heat. After the metal has solidified, the temperature will again drop until it reaches room temperature.

In these alloys the absorption of energy during heating, or energy release during cooling causes a delay in the temperature change while internal energy changes are taking place even though the alloy stays in the solid condition.

These points signify a crystalline structure change in the solid metal, and cause the metal to expand (absorbing heat), or contract while cooling as heat energy is suddenly released. These points are called *critical points.*

The heat treatment of a metal through this crystalline structure change is of great importance.

HEATING METALS DURING WELDING

The carbon content of steel has a vital effect on how various temperatures change its properties.

The heating of steel during fusion welding will ruin the heat treatment or any other properties added during manufacture. To renew these properties, the metal must again be heat treated or mechanically reworked.

See later in this section under "Heat Treatment" for details.

Heating is related to the structure of the crystals in metals. Note in Fig. 118 the schematic shape of crystals for different metals. When iron is heated, for example, it has a different structure than when cooled.

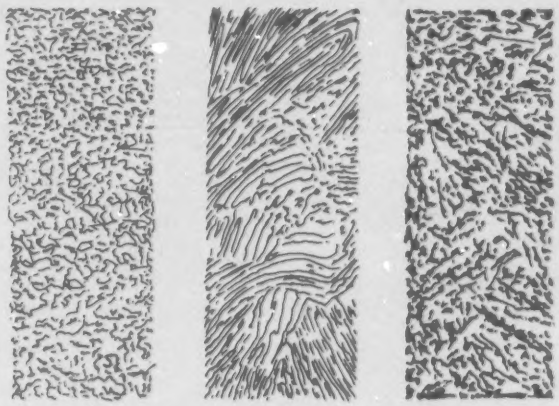

Fig. 119 — Different Iron Structures (Magnified)

When various amounts of carbon are added to iron, the structure of the metal is changed as shown in Fig. 119. The *ferrite* structure is pure iron at lower temperatures, while the *pearlite* is iron with carbon added. The *martensite* is iron with carbon which is rapidly cooled and is hard and brittle.

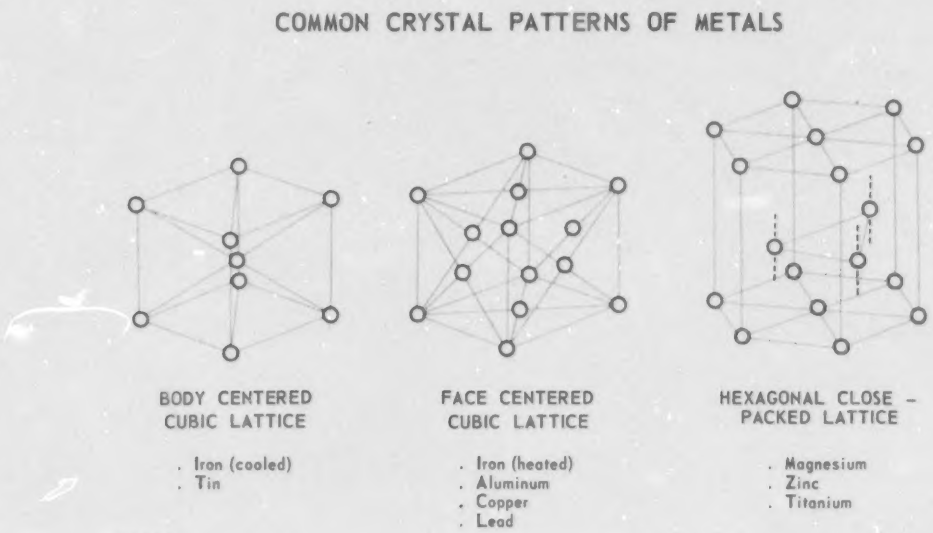

Fig. 118 — Common Crystal Patterns Of Metals

Various heat treatments are used to get different iron and steel properties — hard or soft, ductile or brittle, etc.

HOW TO IDENTIFY IRON AND STEEL

Because of the effect on the properties of steel caused by three variables, carbon content, temperature, and time, a welder must be able to determine accurately the nature of the steel being handled.

The manufacturers' specifications for the particular steel are most desirable. Whenever possible, the welder should obtain these specifications and keep them on file. At the same time, he should mark the metal to correspond with filed information.

Where manufacturers' specifications are not available, other methods may be used to determine the nature of the metal.

The most common tests for shop use are:

1. **Spark test.**
2. **Oxy-acetylene torch test.**
3. **Fracture test.**
4. **Color test.**
5. **Density or specific gravity test.**
6. **Ring or sound of the metal.**
7. **Magnetic test.**
8. **Chip test.**

Of these tests, No. 3 through 8 should take place almost subconsciously in the welder's mind as he works on the metal.

The spark test and the gas torch test must be done under carefully prepared conditions.

These tests will tell with remarkable accuracy the properties of the metal.

SPARK TEST

This method of identifying metals is widely used by welders to identify irons and steels.

A power grinder is used as the test equipment.

When grinding, you must always wear goggles. The grinder must be inspected to see that it is in good condition before proceeding with the test.

When testing a sample, if you touch the rim of the revolving wheel *lightly* with the metal, the friction of the wheel surface as it contacts the metal heats the particles removed to the incandescent and burning temperature.

The sparks resulting from the contact are found to differ in character for different steels.

The *lighter* the contact, the better; use a black background to better identify the spark.

The theory of the spark test is that when a metal is heated, the different parts of the metal oxidize at different rates and the oxidation colors are different.

Relatively pure iron when heated by the grinding wheel does not oxidize quickly. Therefore, the sparks are long and fade out on cooling. As the carbon content of steel or cast iron increases, the compounds of carbon and iron have different ignition temperatures, and therefore the characteristics of the sparks differ.

Four characteristics of the spark generally tell the nature and condition of the steel. They are:

1. *Color of spark.*
2. *Length of spark.*
3. *Number of explosions (spurts) along the length of the individual sparks.*
4. *Shape of the explosions (forking or repeating).*

For example, a mild steel containing 20 point carbon (.20 percent) will show a long white spark which will jump approximately 70 inches (1780 mm) from the power grinder (using a 12-inch (305-mm) wheel). Some of these sparks will suddenly explode, shooting off smaller sparks at approximately 45 degree angles to the direction of travel of the original spark.

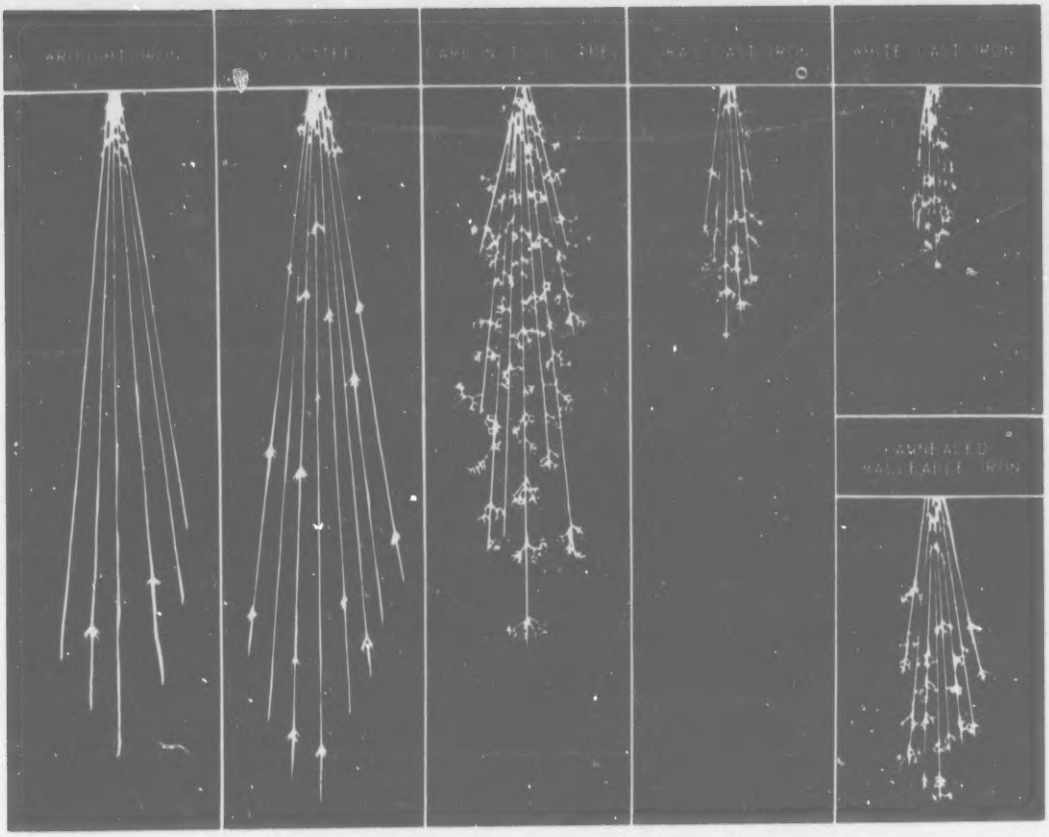

Fig. 120 — Spark Test For Common Cast Irons And Steels

A 30 point carbon steel will have sparks almost identical to the 20 point carbon steel with the exception that more streamlined sparks will explode while the total length of the sparks will decrease slightly. This shows that as the carbon content of steel increases, the explosions of the sparks become more frequent. Also, as the carbon content increases the length of the spark is decreased because of the interruption during their flight of the individual explosions or extremely rapid oxidation of some of the materials in the incandescent particle.

In Fig. 120, for example, a high carbon tool steel, containing 80 point carbon, has a very short spark with explosions occurring so rapidly that it is hard to identify the longer streamlined iron shapes. The sparks dissipate very quickly.

When higher carbon content metals are tested, you may become confused between extremely high carbon steel and cast iron because the spark is somewhat the same. Heat treatments have the same confusing effect on the nature of the spark. The appearance of cast iron and high carbon steel on the basis of the spark are almost identical.

However, the cast iron spark, when leaving the point of contact, is a dull red and the spark jumps only 20 to 25 inches (508 to 635 mm) from the wheel; while the spark from a high carbon steel of approximately 130 point carbon is white, is faster in disappearing, and the length of the spark is usually a little longer. Both of these metals show a small spark explosion at the end of the spark flight. The amount of the spark is considerably less than one would expect from such a high carbon content.

OXY-ACETYLENE TORCH TEST

Even if you know the physical data on a metal, you must also know whether the metal has good welding properties.

For example, some cold rolled sheet steels may show very good physical and chemical properties, but during some part of the manufacturing, impurities have been added to it or certain work was done to the metal affecting its properties to the

extent the metal will not melt readily for welding, will not fuse readily, and final weld may be unsatisfactory.

The usual cause of this condition is that there are impurities imbedded in the metal in the form of slag and roller dirt or excessive sulphur and phosphorus. For these reasons, a welder should subject steel to the torch test.

The actual test consists of melting a puddle in the steel. If the metal is thin, the puddle penetrates through the thickness of the steel until a hole is formed. This puddling should be done with a neutral flame, held at the proper distance from the metal. The puddle should not spark excessively, and it should be fluid. The puddle should not boil, and it should possess good surface tension. The appearance on the edge tells much about the weldability of the steel.

If the metal that was melted has an even, shiny appearance upon soldification, the metal is generally considered as having good welding properties.

However, if the molten metal surface is dull or has a colored surface, and if this surface is rough, perhaps even broken up into small pits or porous spots, the metal is generally unsatisfactory for welding.

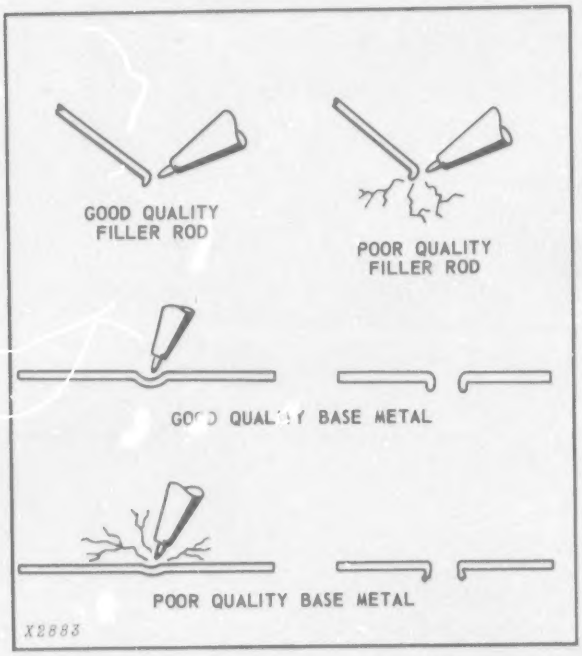

Fig. 121 — Oxy-Acetylene Torch Test Of Metals

This test is accurate enough for most welding and is easy to do. It determines the one thing that is fundamental in any welding job; that is, the **weldability** of the metal.

Fig. 121 shows how this test is made. While performing the weldability test of the metal, be sure to note the amount of sparking emitted from the molten metal.

OTHER METAL IDENTIFICATION TESTS

As an extra precaution, six other tests are occasionally used by the welder.

Fracture Test

The *fracture test* is widely used and is the breaking of a portion of the metal in two. If it is a repair job, the fractured surface is ready for inspection. The appearance of the surface where the metal is cracked shows the grain structure of the steel. If the grains are large, the metal is brittle and weak; if the grains are small, the metal is usually hard and brittle, or soft and ductile. The fracture shows the color of the metal, which is a good way to tell one metal from another, and the test also indicates the type of metal by the ease with which it can be fractured.

The two main divisions of metals include the *irons and steels* which are indicated by their typical gray-white color, and the *nonferrous metals* which come in two general color classifications of yellow and white. Copper may be rather easily identified by a welder and the same applies to brass and bronze. Aluminum, white metal, aluminum alloys, zinc, and the like, are all of somewhat the same silver-gray color, although they may vary in shade.

The metals may also be differentiated by means of the weight or density test of the specimen. A good example of identification by density or specific gravity is identifying aluminum and lead. Roughly speaking, their colors are somewhat similar, but anyone may readily distinguish between the two metals because of their respective weights.

Ring Test

The ring test using the sound of the metal is an easy means of identifying certain metals, after one has had some experience. It is used extensively for identifying heat-treated steels from annealing steels. It is also used to detect alloys from the base metal. An example of the latter is aluminum and

duralumin. The pure aluminum sheet has a duller sound, or ring, than the duralumin which is somewhat harder and has a more distinct ringing sound.

Magnetic Test

The magnetic test is a basic test used to identify iron and steel metals from the nonferrous metals. Generally, all steels are affected by magnetism while the nonferrous metals are not. However, some stainless steels are not magnetic.

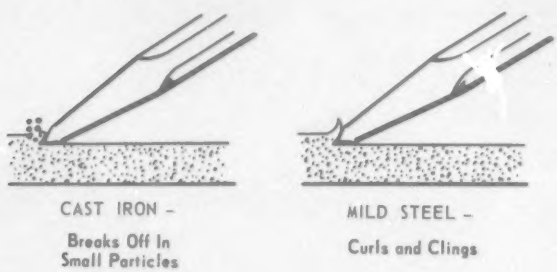

Fig. 122 — Chip Test For Iron And Steel

Chip Test

Another test which requires some experience is the chipping test of a metal. Here the cutting action of the chisel indicates its structure and heat treatment.

Cast iron, for example, when chipped, breaks off in small particles; but with mild steel the chip tends to curl and cling to the original piece (Fig. 122).

The higher-carbon, heat-treated steels cannot be tested in this way because of their hardness.

HOW TO IDENTIFY IRON AND STEEL ALLOYS

Today's iron has been allied with carbon to produce a wide variety of steels for modern uses.

The two main fields are stainless and low-carbon alloy steels. These metals are very difficult to identify, so other tests are needed, as given on the next page.

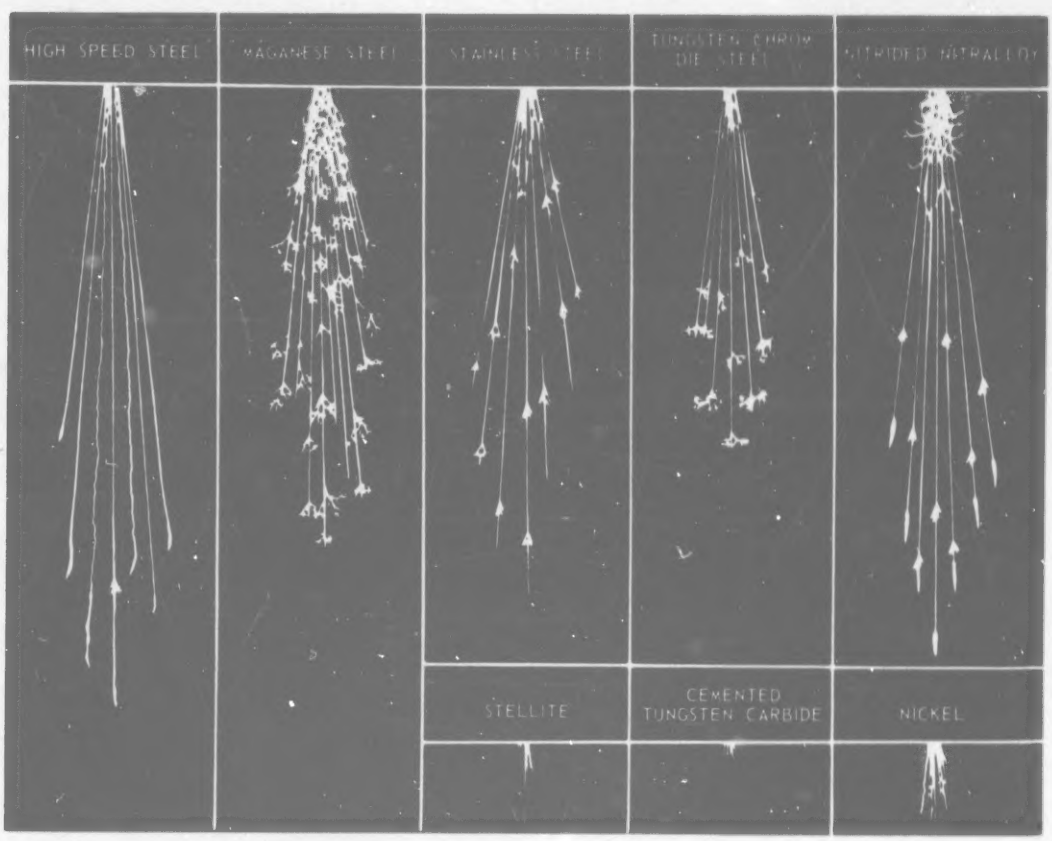

Fig. 123 — Spark Test For Alloy Steels And Other Alloy Metals

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SPARK TEST FOR ALLOY STEELS

The appearance of the power grinder spark for alloy steels varies considerably, depending on the alloys included in the metal.

The basic test, the iron-carbon spark, is identical with the straight, iron-carbon steels. The number of the spark explosions increases as the length of the spark flight decreases, and the color of the spark becomes brighter and brighter as the carbon content increases.

The major variations the alloy elements give to a steel are the multitude of right-angle, branch-off sparks which result from the different incandescent colors of the alloys in the metal (the change of color of the spark).

For example, a manganese steel has only a slight hint of the spark explosion, but the manganese causes the sparks to shoot out at right angles to the flight of the original spark, and these sparks tend further to explode (repeating sparks), producing the appearance of a leafless tree branch (Fig. 123).

Tungsten-chromium steels, which are used for high-speed work, show the typical, high-speed steel spark except that the spark turns to a chromium yellow (straw color) at the end of its flight. The chromium and the tungsten reduce the carbon spark, causing it to be very fine or thin with repeating spurts.

TORCH TEST FOR ALLOY STEELS

Generally, the higher the alloy content, the more difficult it is to weld the metal. Under the torch flame, these metals have a tendency to boil, because of the action of the alloys in them, and special fluxes are often used when welding them.

Stainless steels are difficult to flame weld, and a flux is needed to produce good welds. Without the flux, the metal boils and a porous puddle is produced.

Manganese steel is often used for surfaces which are exposed to abrasive wear, such as power shovel buckets. The usual application of welding in this case is to build up the worn surfaces (see Part 5). The steel melts readily under the torch flame and presents few difficulties in welding.

Nickel steels can be identified under the torch flame by the boiling action of the metal. Nickel-chrome steels behave in much the same way.

OTHER TESTS FOR ALLOY STEELS

The color test, ring test, magnetic test, fracture test, and the chip test are all applicable to alloy steels, but perhaps the easiest one is the *color test.*

The different alloys tend to change the color of the metal, which in some compositions is easy to identify.

Stainless steels, for example, have a distinct silvery color, which sets them apart from the other steel alloys.

Some of the metals are magnetic, while others are not. Identification can be done to a certain extent by using this test.

The chip test is not widely used because of the similarity in the appearance of practically all the stainless steel alloys. However, some of these alloys are considerably harder than others, and the chip test will bring this out quite clearly.

The ring or metallic sound of the metal is another test which can be applied to steel alloys with considerable accuracy. However, this test should be used in addition to the other tests.

HEAT TREATMENT OF METALS

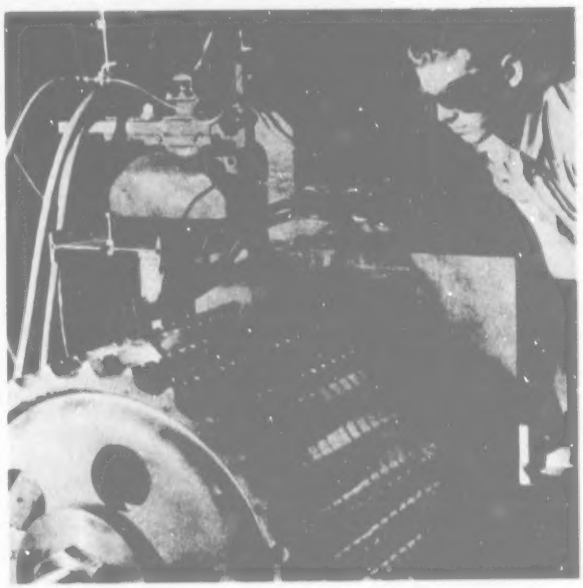

Fig. 124 — Heat Treating To Harden Gear Teeth

The welder should be particularly interested in **heat treatment** of metals, because he must know what welding does to the heat treatment of the metal and its effect on the physical properties.

It is necessary to know if a metal must be preheated for welding, and if the metal should be heated during the welding operation. You must know too, what heat treating procedure to use, to bring back as nearly as possible, the original properties of the metal. (This is the postheat treatment.)

The most common application of heat treating in a welding shop is *annealing* to relieve the metal of internal stresses and strains, caused by the expansion and contraction during welding; and to improve the properties of the metal in the weld.

Most structural welding in shops involves only the knowledge of how a metal can be annealed.

It is in job welding — involving the repair of broken parts — that an accurate knowledge of all phases of heat treating by the welding operator is most needed.

PURPOSES OF HEAT TREATMENT

All metals can be heat treated. Some metals are affected very little, but some, particularly most steels, are greatly affected.

Heat treating may serve the following purposes:

1. *Develop ductility.*
2. *Improve machining qualities.*
3. *Relieve stresses.*
4. *Change grain size.*
5. *Increase hardness or tensile strength.*
6. *Change chemical composition of metal surface as in casehardening.*
7. *Alter magnetic properties.*
8. *Modify electrical conduction.*
9. *Induce toughness.*
10. *Recrystallize metal which has been cold worked.*

When **heat treating,** there are three factors of prime importance:

1. The temperature to which the metal is heated.

2. The length of time that the metal is held at that temperature and speed of cooling.

3. The material surrounding the metal when it is heated, as in case hardening.

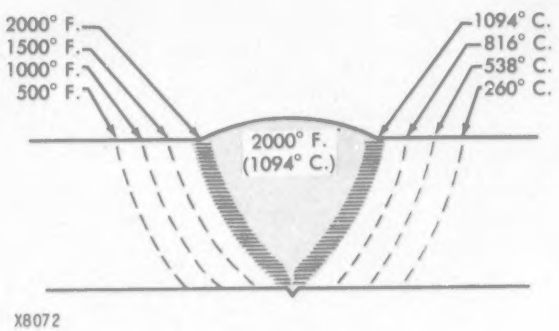

Fig. 125 — Temperature Zones in The Weld Area During Welding

When a weld is made, the metal in and around the weld joint is heated to a variety of temperatures as the distance from the weld joint increases. This drop in the metal temperature from the weld joint outward is called a *temperature gradient.*

In steels, some of the metal in the area of the weld is heated through only *one* critical point, some through *two* points, and some may be heated to only 500°F (260°C) as shown in Fig. 125.

Because of the uneven heating, the strength, ductility, grain size and other metal properties may vary greatly and this may affect the strength of the metal in the weld area.

The welding operator may use preheating, concurrent (continuous) heating. and/or postheating to avoid temperature gradients in the weld area.

Heating the metal *before* welding helps to prevent internal stresses and strains which may cause weld failure. The welder may use *continuous heating* for the same purpose, and may use *postheating* to relieve stresses and bring all the metal in the area of the weld to the same heat treated condition.

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HOW TO HEAT METALS

Heating metals is a complex operation. All metals expand when heated and rather drastic changes in volume take place as metals are heated above their critical temperatures. The same is true when they are cooled below their critical temperatures (where a crystalline structure change takes place).

Unequal heating or cooling may cause cracks, or at least, a warping of the structure. However, this action is not always a disadvantage, as warped parts can be also straightened using this technique.

Local heating can be done by using any of these flames:

1. **Air-fuel gas.**
2. **Oxy-fuel gas.**

Or, it can be done by:

1. **Electrical resistance heating.**
2. **Induction heating.**
3. **Localized furnaces.**

ELECTRICAL RESISTANCE HEATING is done by either putting electrical resistance units against the parts to be heated or by using electric resistance units to heat a furnace.

INDUCTION HEATING is a way of heating using high-frequency alternating current to create eddy currents in the metal. This method heats a metal throughout its thickness.

LOCALIZED FURNACES are normally used for general heating of metals. The furnace can be heated with direct heat or indirect heat using air-fuel gas, electrical induction, or electrical resistance units.

HOW METALS ARE COOLED

The speed and evenness of cooling of a metal object is a major factor in the physical properties of the metal.

Welds performed on steels at room temperature cool quickly, and because the cooling takes place from the molten condition, the crystals are large. Cooling may be done in various ways. The heat loss is a combination of:

1. **Convection.**
2. **Conduction.**
3. **Radiation.**

The problem in heat treating is to cool the inside of the metal at the same speed as the surface.

Air is a common gas cooling medium. Others are thermal convection cooling (still air), forced convection cooling (fans), and water cooling.

PROPERTIES OF STEEL

Steel can be obtained with various carbon contents and alloying metals. The chart below shows the carbon content of some common items made of steel (most are *fractions* of one percent).

The family of steels starts with low-carbon steel (almost wrought iron). As the carbon content increases, the steel becomes harder, stronger, and more brittle until approximately 1.75 percent of combined carbon is reached. This is the maximum percent of carbon that will combine with iron to form steel.

Metal Part	Carbon Content %
Boiler Plate	.12
Castings, Low Carbon Steel	.20 (max.)
Case Hardened Steel	.12
Cold Chisels	.75
Files	1.25
Forgings	.30
Gears	.35
Hammers	.65
Lathe Tools	1.10
Machinery Steel	.35
Metal Tools	.95
Nails	.10
Pipe, Steel	.10
Rails	.60
Rivets	.05
Set Screws	.65
Shafts	.50
Springs	1.00
Steel for Stamping	.90
Tubing	.08

CRYSTALLINE STRUCTURE OF STEEL

Practically all heat treatments deal with the crystalline structure of steel, or the grain size. They are also concerned with combinations of iron and carbon, and with the distribution of iron carbide in the metal.

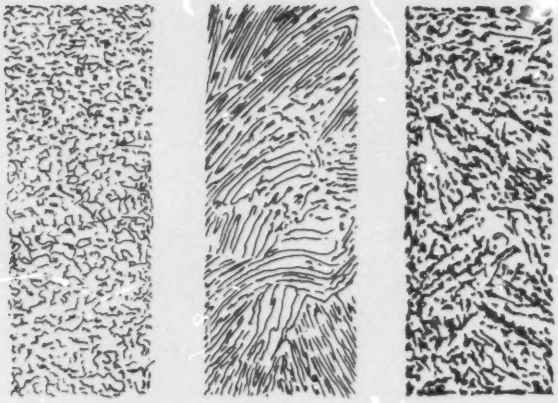

Fig. 126 — Different Iron Structures (Magnified)

In 10 point carbon steel, which contains 1/10 of one percent carbon, all of the carbon is in chemical combination with iron, forming iron carbide, Fe3C. There is considerable free iron remaining, which in metallurgy is called ferrite.

Steel containing a large amount of ferrite cannot be hardened. The only heat treatment possible is to alter the grain structure and size.

Heating a steel to its upper range (critical temperature) does not greatly affect the steel because it is the iron carbide which determines the hardness.

Iron carbide, mixed in various proportions with ferrite, gives several combinations of hardness and brittleness, depending on various heat treatments. The hardness levels have been given names.

In the order of their hardness these steels are:

1. **Austenite,** soft, ductile, tough, and wear resistant.

2. **Martensite,** (Fig. 126) is the first stage of austenite decomposition and a brittle constituent.

3. **Troostite,** not quite as hard as martensite, but is considerably tougher. This is the constituent of steel used in files.

4. **Sorbite,** not as hard as troostite, but it is tougher. Because of its high yield point it is the structure of spring steels.

5. **Pearlite** (Fig. 126), the toughest structure and has the highest breaking strength.

How Various Steels Are Obtained

The various forms of steel are obtained by the following steps:

1. **Heating.**

2. **Quenching**

3. **Drawing.**

4. **Tempering.**

Eighty-five point crystalline steel has the correct amount of carbon to form steel that has the lowest critical temperature. When properly heat treated, the whole structure of this steel becomes pearlite. Pearlite is a steel which under the microscope has alternate layers or rows of iron carbide and ferrite (Fig. 126). These beads look similar to a fingerprint printed with black ink on white paper. This is the only steel that has just one critical temperature.

The hardness of a steel which has been heated above the critical temperature, as in welding, may be affected by controlling the *rate of cooling.*

If the steel sample above is heated to 1250°F (677°C) and is then quenched in cold brine, austenite is formed.

If it is heated to 1250°F (677°C) and is quenched in cold water, martensite is formed.

By heating the steel to its critical temperature and quenching it in oil, troostite is formed.

If it is heated to 1250°F (677°C), and quenched in a molten metal bath, sorbite and pearlite are formed.

The above steps shows that the rapidity of cooling affects the distribution and clustering of the iron carbide. Therefore, *quenching*, or the rate of cooling, has much to do with the type of steel obtained.

To get the results described above in another way, proceed as follows:

1. Heat the eighty-five point carbon steel to 1250°F (677°C).

2. Quench in cold brine for an austenite.

3. If martensitic steel is desired, reheat the sample to 400°F (205°C) and cool again.

4. If troostite is desired, reheat the sample to 600°F (316°C) and cool.

5. If sorbite is desired, reheat to 800°F (427°C) and cool.

6. When the metal is reheated to 1000°F (538°C) and cooled, pearlite is formed.

The temperatures to which these various forms of steel are heated overlap, so that in many cases, one may have a steel which is part sorbite and part troostite, or part sorbite and part pearlite.

These temperatures must be held constant (±25°F (14°C) and the part must be left in the furnace at this temperature until it is fully heated throughout its thickness.

ANNEALING OF STEEL

Annealing includes several types of heat treating operations.

Generally, annealing is considered a heat treatment which *refines the grain and leaves the metal in a soft condition.*

An annealing operation may be performed for several reasons:

1. So the metal may be worked cold.

2. To make the steel machinable.

3. To relieve the internal stresses produced while the metal was being shaped or welded.

When performing field welds, practical ways to preheat and anneal metal are with the oxy-acetylene torch, or by induction heating.

In induction heating, electrical coils are wrapped around the part and high-frequency AC electricity is passed through.

To fully anneal most steels, do the following:

1. Heat the steel slightly above its critical temperature.

2. Cool the steel as slowly as possible.

If the grain size is of no importance, you do not have to be careful of the exact temperature to which the steel is being heated. As the grain size increases, the elastic limit and ductility of the metal decreases.

Steel, upon being heated to the critical temperature, changes its crystalline structure and reaches its most refined grain condition at its lowest critical temperature.

However, if the steel is heated above this temperature, the grain size starts to grow and becomes larger as the temperature rises. Upon being cooled, the steel will retain the size of the maximum crystalline structure reached. The crystals will continue to grow if the piece is kept at the maximum temperature, or if kept above its critical temperature until a maximum size is reached. Therefore, the speed of welding and the rapidity of cooling has some effect on crystal size.

This is particularly important in welding because both the weld metal and the metal adjacent to the weld are heated considerably above the critical temperature.

Upon cooling a weld, regardless of the speed of cooling, the crystalline structure in the weld, and in the steel adjacent to the weld, will be large and the strength and hardness of the metal will be reduced.

Two methods may be used to remedy this condition:

1. Pound the metal with a hammer as it is cooling (peening). The peening will refine the grain structure.

2. Allow the metal to cool to room temperature; reheat to just slightly above the critical temperature of the metal and then allow it to cool slowly.

Peening affects the grain size only in the area worked, usually at the surface. Therefore, method No. 2 is preferred.

Industries with the facilities put the whole steel structure, which has been welded, in an annealing furnace; thus the whole structure is annealed instead of just the weld and the parts adjacent to it.

Commercial annealing (partial annealing) may be done at a temperature between 1100 and 1200°F (593 and 650°C). This process is used mainly to relieve internal stresses.

HARDENING OF STEEL

Steels of less than 50 point carbon content cannot be sucessfully hardened by heat treatment. Steels above 170 point carbon content are also difficult to harden by heat treatment. Within these extremes it is possible to obtain almost any degree of hardness by using the proper carbon content and the proper heat treatment.

It is also common practice to obtain a refinement of the grain structure along with the hardness.

Percent of Carbon in Steel	Critical Temperature For Hardening and Full Annealing (°F)(°C)
.10	1675-1760 (914-959)
.20	1625-1700 (886-927)
.30	1560-1650 (850-900)
.40	1500-1600 (816-872)
.50	1450-1560 (788-850)
.60	1440-1520 (783-827)
.70	1400-1490 (760-811)
.80	1370-1450 (744-788)
.90	1350-1440 (733-783)
1.00	1350-1440 (733-783)
1.10	1350-1440 (733-783)
1.30	1350-1440 (733-783)
1.50	1350-1440 (733-783)
1.70	1350-1440 (733-783)
1.90	1350-1440 (733-783)
2.00	1350-1440 (733-783)
3.00	1350-1440 (733-783)
4.00	1350-1440 (733-783)

Generally, to *harden* a steel specimen in this range of carbon content, the steel is heated just above its critical temperature and then cooled rapidly. The critical temperatures for steel with various carbon contents are shown in the chart above.

As we mentioned earlier, the rapidity of cooling determines to a great extent the hardness and brittleness of the metal. Cold brines, cold water, air and molten metal baths, are used as mediums for cooling metal rapidly.

The water cooling and the brine cooling result in extreme brittleness along with hardness. Air cooling and molten-metal-bath cooling tends to relieve much of the brittleness, but at a sacrifice of some hardness.

The hardness of the metal seems to depend on the distribution and structure of the iron carbide throughout the steel. When cooled rapidly, there is little opportunity for the iron carbide to separate or segregate, but as the rate of cooling is slowed, the carbides have time to separate and the metal becomes progressively softer.

TEMPERING OF STEEL (DRAWING)

Quenching a steel sample in a molten-metal bath will produce a hard metal without too much brittleness. However, a more effective method is called "drawing the hardness" or *tempering*.

By reheating the steel sample to a temperature between 400 and 1000°F (205 and 538°C) after hardening it, much of the brittleness in the steel can be relieved: most of the internal stresses and strains are also relieved.

Reheating the metal to 600°F (316°C) (blue color on the steel surface) is probably the most common drawing or tempering operation.

FLAME HARDENING

Oxy-acetylene *flame hardening* is being widely used today in manufacturing (Fig. 127).

In many parts such as gears, shafts, and connecting rods, it is advisable to produce as hard a wearing surface as possible, and yet keep the inside of the structure in a ductile and tough condition. The hard surface provides long wear and maintains an exact contour, while the tough interior insures that the part will withstand shocks without breaking.

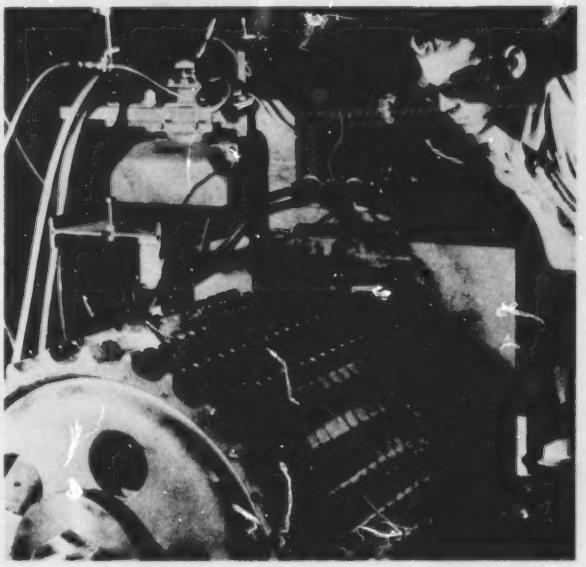

Fig. 127 — Flame Hardening Of Gear Teeth

In flame hardening, the part is heat treated and then drawn to produce a tough, ductile structure throughout. The surfaces to be hardened are then put in a flame-hardening machine. A multiple-tipped oxy-acetylene flame is passed over the surface to heat it quickly to a high temperature (Fig. 127). Following the flame, a heavy stream of water is automatically fed to the surface, which quickly cools the entire surface.

The depth of the hardness can be accurately controlled by the temperature of the cooling agent.

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CASE HARDENING

Another way of producing a metal part with a tough interior and a hard-wearing surface is known as **case hardening.**

The process is to make the part out of low carbon steel, so any machining required may be done easily. The surfaces to be hardened are then exposed to carbon while they are at a high temperature. The heated iron will absorb some of the carbon, increasing the carbon content of the surface, which may then be hardened by the simple heat treating process.

This is called the spherodizing process. Typical examples of this method are piston pins and camshafts in engines.

Where it is not desirable to case harden certain portions of the part exposed to the carbon at high temperatures, these portions may first be copper plated.

Generally, the carbon will penetrate into the steel to a depth of ¼ inch (0.4 mm) per hour. However, the depth will vary with the temperature, kind of carbon used, and the steel to be case hardened.

To heat treat a case hardened part, do the following:

1. Heat the steel to its critical temperature and quench it. This produces a glass-hard exterior on parts which have been exposed to the carbon bath. This also produces a tough interior with a refined grain which is of low carbon content and which is therefore strong and ductile.

2. Then reheat to a temperature between 400 and 900°F (205 and 483°C) to draw (temper) the surface.

HEAT TREATING OF ALLOY STEELS

The **heat treatment** of alloy steels is difficult because of the many alloy ingredients, and the hundreds of combinations of these alloy metals with the iron carbon steels.

Generally, alloy metals lower the critical temperature of the iron carbide steel.

Some alloy metals have a special influence on the characteristics of the heat treatment. For example, iron carbide steel, with manganese added to it as an alloying metal, will become a self-hardening steel.

If a sample of manganese steel is heated to its critical temperature [1350°F (1317°C)] and cooled in air, the sample is as hard as an ordinary iron carbide steel sample quenched in cold water. Further, this alloy has the characteristic of maintaining its hardness at high temperatures. This characteristic makes it useful as a metal-cutting tool.

Chromium-tungsten high speed steel also has the property of maintaining hardness at a high temperature.

It is difficult to anneal these steels because of their self-hardening properties.

To heat treat alloy steels properly, you should, if possible, obtain the exact percentage of the constituents in the steel, and use the recommended process as specified by the manufacturer of the steel.

HEAT TREATING OF CAST IRON

There are several forms of cast iron:

1. White cast iron.

2. Gray cast iron.

3. Nodular iron and malleable iron.

All are similar cast irons in their carbon content and method of manufacture, except for the nodular irons, which have other alloying metals in them.

They *differ* because of the heat treatments.

WHITE CAST IRON is formed by heating cast iron to the critical temperature [1650 to 2098°F (900 to 1143°C)] and cooling rapidly. This cast iron gets its name from the appearance of the fracture, which is white as a result of the carbon being in solution with the iron, forming cementite and pearlite.

If cast iron is heated to its critical temperature, and then cooled slowly (in asbestos, sand, or a furnace), the slow change through the temperature ranges permits enough time for some of the excessive carbon to separate from the iron to form microscopic flakes of graphite. When a sample of this type of cast iron is broken, the fracture has a *grayish* color because of the number of graphite flakes imbedded in the cast iron body.

White cast iron, because of the excessive amount of carbide, is too hard to machine, whereas gray cast iron, because of the presence of the graphite flakes and the reduction of the amount of carbide is machinable.

MALLEABLE IRON is cast iron heat treated to make it more ductile, and more resistant to shock. This type of cast iron is formed by heating a casting to its critical temperature and cooling it rapidly, forming white cast iron; then reheating to a temperature between 1450 and 1650°F (788 and 900°C), and keeping it at this temperature for 24 hours for each inch (25 mm) of casting thickness. Being kept at this high temperature for this long causes much of the carbon to separate slowly from the iron in the casting, forming globular carbon (spheroids of carbon or small microscopic pools of carbon surrounded by low carbon iron). After heat treatment at this high temperature for the proper length of time, the casting is cooled slowly.

We can now see that if a malleable iron casting is welded, the casting will lose its malleable qualities in the weld and in the vicinity of the weld.

For this reason, *never weld on malleable iron castings*. Instead, they should be brazed or braze welded to keep the temperature below the point where white cast iron is again formed.

TEST YOURSELF

QUESTIONS

1. What are the two major groups of metals?

2. Which melts at a higher temperature, cast iron or mild steel?

3. What is the difference between an iron and a steel?

4. Match the items on the left below with the correct item at the right.

a. Tensile strength	1. Ability to resist penetration.
b. Ductility	2. Ability to resist pulling apart.
c. Malleability	3. How easily a metal fractures.
d. Hardness	4. Ability to be stretched.
e. Brittleness	5. Tendency to be hammered into shape.

5. If you chip a metal with a cold chisel and it curls, would it be a mild steel or a cast iron?

6. True or false? "Annealing is the hardening of metals by heat treatment."

7. How does malleable iron differ from cast iron?

8. What happens if malleable cast iron is welded?

(Answers on page 122.)

WELDING SAFETY / PART 8

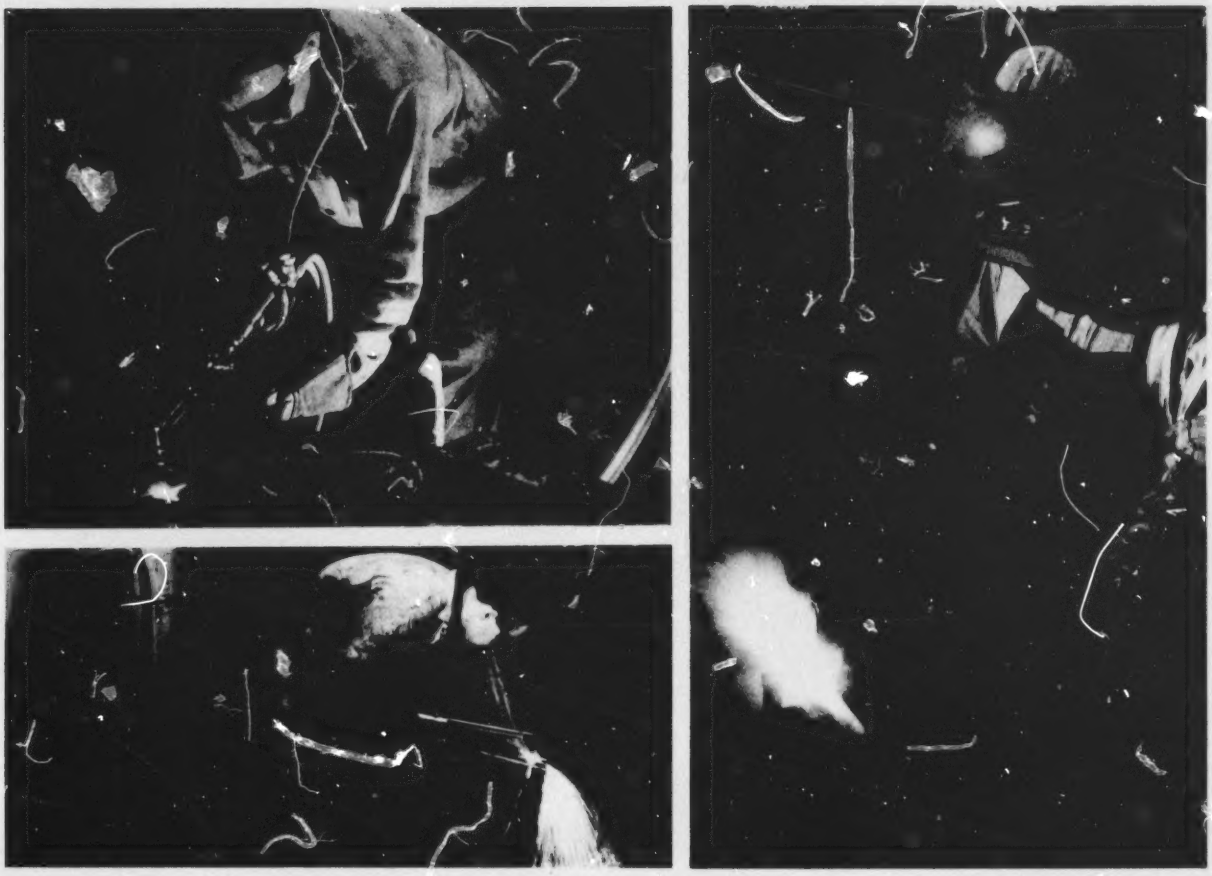


Fig. 128 — Safety in Welding

INTRODUCTION

We learn by experience. But learning safety through your own personal experience would be foolhardy — and unnecessary.

The safety rules for welding given here are based on someone else's experience. For your own good, learn these rules **before** you start welding. Someone learned them the hard way.

For more complete safety recommendations, refer to the joint American Welding Society AWS-ANSI Standard Z49.1-1967.

When safety precautions refer to acetylene, they apply as well to other fuel gases such as natural gas, propane, hydrogen, etc.

PROTECTIVE EQUIPMENT
(For Arc and Oxy-Acetylene Work)

Always wear goggles with suitable filter lenses when using a torch. Also wear a head shield or helmet with suitable filter plates when arc welding. Wear flash goggles having side shields and suitable lens at all times — even when adjusting controls, etc. Goggles and helmets protect your eyes from sparks and flying slag, and also from the strong light and injurious rays of the flame or arc. They also help you to see your work better.

Wear leather or asbestos gloves and aprons, and suitable shoes and other protective clothing (Fig. 129).

Keep protective equipment dry and free of oil.

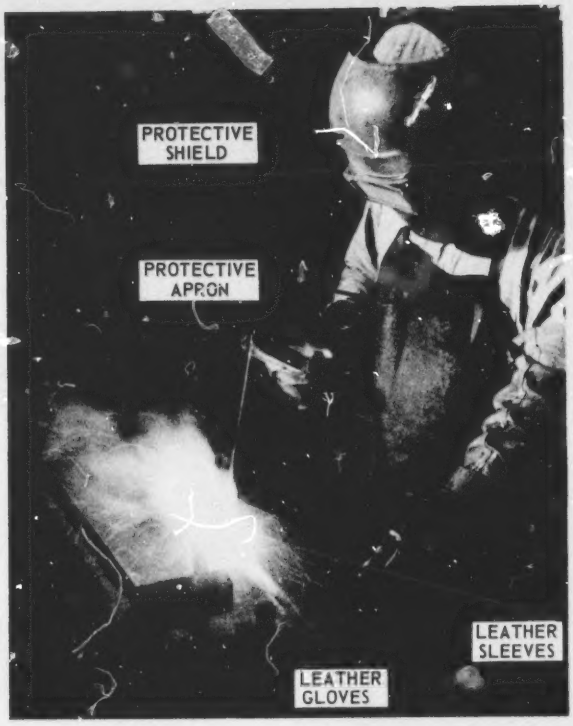


Fig. 129 — Protective Clothing for Welder

Take care that your own clothing is not oily and that pockets and cuffs are not open and ready to receive sparks or hot slag.

Don't use rope to suspend staging for support of cutting or welding operations.

VENTILATION

Working areas must have adequate ventilation. When toxic fumes from lead, cadmium, or beryllium materials or any other substances are present in harmful concentrations, always use an air-supplied respirator.

Make sure that oxygen concentrations above normal cannot develop in the work area.

Never use oxygen for ventilation — that is, never try to replace oxygen in the atmosphere that has been consumed during a welding or cutting operation – ventilate with air.

Avoid leaks or open valves in small enclosures. Leave gas cylinders outside when working in such enclosures.

Don't weld or cut for at least 15 minutes after contamination of clothing with oxygen.

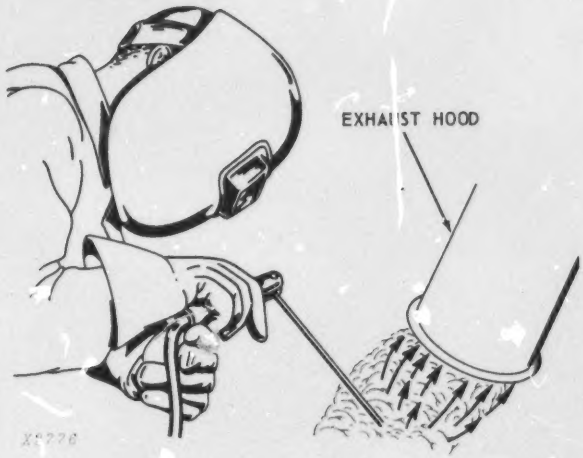


Fig. 130 — Welding Areas Must Have Ventilation

WORKING ON TANKS AND CONTAINERS

Welding of containers should be done only by personnel familiar with American Welding Society's standard practice recommendations (A.W.S.-A6.0-65).

Don't weld or cut containers such as drums, barrels, tanks, until you know there is no danger of fire or explosion.

Don't depend on your eyes or nose to decide if it is safe to weld or cut a closed container — find out what was in the container or use an explosimeter. A very small amount of residual flammable gas or liquid can cause a serious explosion.

Never use oxygen to ventilate a container.

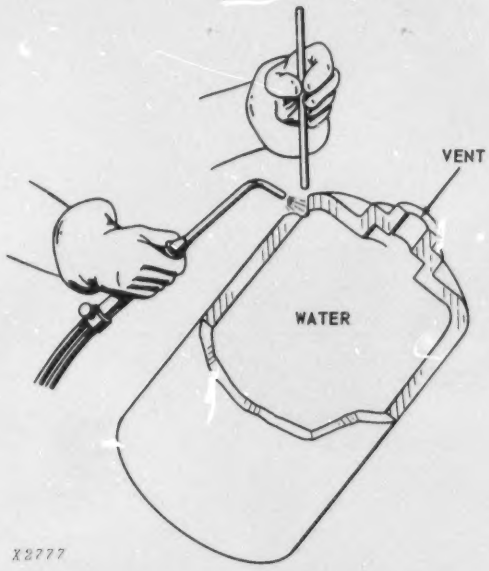


Fig. 131 — Proper Way to Weld a Container

When you know the container held a gas or liquid which will readily dissolve in water:

(1) **Flush out with water** several times and *then fill with water* as far as work permits, positioning container to permit introduction of as much water as possible (Fig. 131).

(2) Before welding or cutting, be sure there is a vent or opening to provide for release of air pressure as shown.

When you know the container held a gas or liquid which will not readily dissolve in water:

(1) Clean out thoroughly with steam or a cleansing agent and fill with an inert gas such as carbon dioxide or nitrogen before repairing. Carbon dioxide is heavier than air and will tend to remain in the container if the opening is at the top.

(2) Use steam to clean out light materials.

(3) Use a strong caustic soda solution to clean out heavy oils or grease.

(4) Be sure to fill with inert gas, such as nitrogen or carbon dioxide, no matter how well you have cleaned — there may still be traces of oil, grease, or other readily oxidizable material under the seams.

Be careful when cleaning with steam or caustic soda — wear goggles and gloves.

Don't clean where there is poor ventilation. Ventilation is necessary to carry away harmful or explosive vapors.

When scraping or hammering to remove heavy sludge or scale, use a spark resistive tool and keep it wet to avoid sparks.

Keep your head and arms as far away from your work as possible.

FIRE PREVENTION

Fires may result from gas or arc welding and cutting operations if combustible materials are allowed to come in contact with *flying sparks, falling slag, not metal,* or the *arc of flame* itself.

Remember:

- *flying sparks can travel as much as 35 feet (10.7 m)*
- *falling slag can pass through cracks out of sight of the goggled operator, or*
- *the metal being cut or welded (or the arc or flame itself) can be hot enough to ignite combustibles.*

To prevent fires:

1. *Keep flames and sparks away* from cylinders and hose.

2. *Move the job,* if possible, to an area free of combustibles. Never work near explosive atmospheres. Avoid paint spray rooms, dip tanks, storage areas, ventilators, etc.

3. ***Move combustibles*** **at least 30 to 40 feet (9.2 to 12.2 m) away from the job. Sweep the floor before lighting torch. Wet down wooden floors.**

4. *Cover combustibles* with fire resisting shields or covers, if they cannot be moved. Covers should be large enough to completely shield the material and tight enough to prevent sparks from going under, over, or between the covers to the material. Use heat resisting asbestos shields to protect nearby walls, ceilings and floors.

5. Use stand-by *watchers* equipped with suitable fire extinguishers where the risk of serious fire damage is great.

6. *Inspect the area* on completion of the job to make sure that it is free of sparks, glowing embers and flames.

7. *Do not bring cylinders into confined spaces.*

8. *Avoid oxygen leaks* in enclosed spaces. Do not leave oxy-fuel gas torches in enclosed spaces when not in use.

9. Never use oxygen to dust off clothing or work. A spark will cause clothing in an oxygen atmosphere to burst into flame immediately.

10. *Never use oxygen* in pneumatic tools, in oil preheating burners, to start engines, to blow out pipelines, to create pressure in a container — or anywhere, as a substitute for compressed air or other gases.

FIVE RULES
(For Safe Handling of
Oxy-acetylene Equipment)
1. Keep oxy-acetylene equipment clean, free of oil, and in good condition.
2. Avoid oxygen and acetylene leaks.
3. Open oxygen valves slowly.
4. Purge oxygen and acetylene lines before lighting torch.
5. Keep heat, flame, and sparks away from combustibles.
GAS
OIL
X2778

Fig. 132 — Five Rules For Safe Handling of Oxy-Acetylene Equipment

OXY-ACETYLENE SAFETY

Oxy-acetylene welding safety will be covered under the following subjects:

- **Cylinders**
- **Torches and Regulators**
- **Hoses**
- **Setting Up**
- **Adjusting Pressures**
- **Operating the Torch**
- **Backfires and Flashbacks**
- **Stopping Work**

Let's look at safety for each subject in detail.

CYLINDERS

Use approved cylinders. They are safe so long as they are properly handled. **Don't drop cylinders.**

Always call acetylene "acetylene" — not "gas." Call oxygen "oxygen" — not "air." The word gas is a general term and confusion here is dangerous. The use of the term "air" instead of the word "oxygen" may lead to serious accidents.

Identify gas content by the *name marked on the cylinder*. If the cylinder is unmarked, do not use it! Return it to the supplier. Do not rely on color codes.

Never use a cylinder or its contents for other than intended purposes.

Keep oil and grease away from cylinders and cylinder valves.

Separate oxygen from fuel gas cylinders in storage.

Keep cylinders away from exposure to sparks, hot slag, open flame and all possible sources of excessive heat.

Be careful that cylinders are not placed so as to become a part of an electrical circuit. Avoid third rails, wires and electric welding circuits.

Never strike an arc on, or tap an electrode against a cylinder.

Take care to place cylinders clear of passageways for personnel and equipment.

Always secure upright cylinders to a suitable support with a chain or other holder (Fig. 133).

Always transport, store and use acetylene cylinders in the vertical position to avoid "spitting" acetone.

When transporting cylinders by crane, use cradle, platform or other suitable support.

Never lift the cylinders by slings, by the caps or by electric magnets.

Never use cylinders as support or rollers.

Never try to mix any gases in a cylinder.

Never try to refill a cylinder.

Mark empty cylinders "Empty" or "MT."

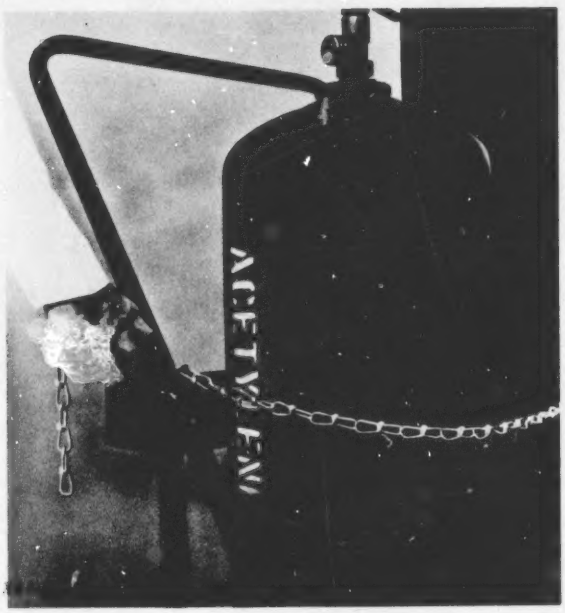


Fig. 133 — Always Secure Upright Cylinders

Send "Emptys" back to the supplier promptly.

Keep "Emptys" and "Fulls" separate.

Never tamper with or alter cylinder numbers or other markings. This is not only foolish but may be illegal.

Do not tamper with or change fittings on cylinders.

If valves cannot be opened by hand, do not use hammer or wrench. Notify supplier.

Leaks may be found in acetylene cylinder valves, when valves are open, that cannot be stopped by closing the valve and tightening the packing gland. Leaks may also be found at acetylene fuse plugs or in the cylinder. If these types of leaks are found (1) remove cylinder out of doors away from possible sources of ignition; (2) tag cylinder properly to explain the trouble; (3) notify supplier as soon as possible.

Protect cylinder valves from bumps, falls, falling objects, and from weather. Keep them covered with cylinder caps when moving cylinders.

Keep valves closed on empty cylinders.

If an adapter is required between cylinder and regulator, always use a standard adapter. These may be obtained from your supplier. Where right- and left-hand threads are used on adapter, use two wrenches to insure leakproof connections.

Never use other than approved wrenches for opening acetylene cylinder valves not equipped with handles. These should be obtained from the suppliers.

Do not store cylinders in unventilated areas.

TORCHES AND REGULATORS

Do not work with defective equipment. Have leaking or damaged equipment repaired by authorized servicemen.

Give Your Oxy-Acetylene Equipment the Same Good Care and attention you would any other dependable tool. Your work will be easier — and safer.

Keep your equipment clean.

Oil and grease in the presence of oxygen may burn with explosive violence if ignited. Do not use oil, grease or other readily oxidizable substances on any torch or regulator. Do not handle equipment with oily rags or gloves.

Inspect union nuts, connections and all seating surfaces on regulators and torches before use. Damaged connectors should be removed and faulty seats repaired at once — they are apt to cause fires, backfires or flashbacks.

Never connect a regulator to a cylinder containing a gas other than that for which the regulator is designed.

If a regulator shows excessive creep (pressure building up when torch valves are closed), close cylinder valve and have regulator repaired at once.

Have pressure gauges on regulator tested periodically for accuracy.

If the pressure gauge needle does not return to the stop pin when pressure is released, do not merely adjust the pin. Have the gauge checked for accuracy.

Never test or calibrate regulator pressure gauges with oil.

Never use a torch as a hammer or to knock slag from work. Deformation of the torch or tips may cause trouble. Keep slag hammers and wire brushes handy.

Never use a hard, sharp tool for cleaning tips, except where specifically recommended by the tip manufacturer. Use appropriate tip cleaners or a copper or brass wire. When possible, clean orifices from the inner end. An oversize or bellmouth orifice may lead to trouble.

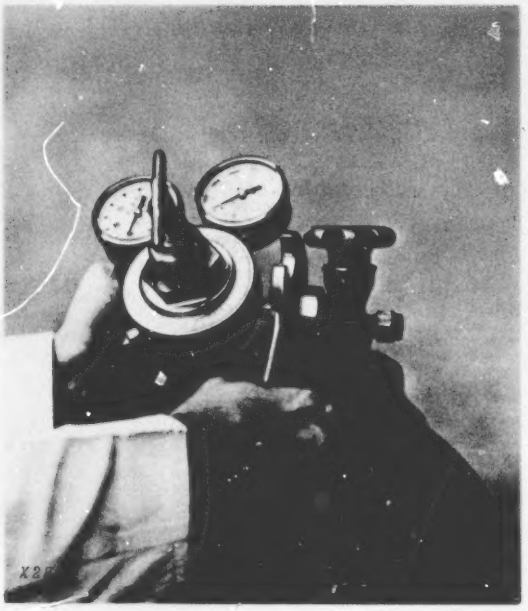


Fig. 134 — Use Special Wrenches To Make Connections (If Recommended)

Make connections using wrenches designed for that purpose (Fig. 134). A standard wrench which fits your connections may be obtained from your supplier. Wrenches need not be used on connections using an O-ring seal which can be made gas-tight by hand.

If a leak develops around the torch valve stem, tighten the packing nut. If necessary, have valve repacked. *(Use only packing* supplied or *recommended* by the torch *supplier.)*

The gases used on oxy-acetylene jobs should never be drawn from cylinders except through properly attached pressure regulators approved for oxygen or acetylene service. *Uncontrolled, pressure is dangerous in itself.* The regulator, properly adjusted, also acts as a safety device tending to stop any flashback from entering the cylinder, (or manifold) where it might cause serious damage.

HOSES

All new hose is dusted inside with talcum powder — blow this out before using.

Use only hose designed for use with the gas source to which it is to be connected.

Hoses should be color-coded to avoid mixing, and a groove in the nut will generally indicate a left-hand thread. Oxygen hoses are usually green, while acetylene hoses are normally red — but be sure.

Standard hose connections are threaded, right-hand for oxygen and left-hand for acetylene, to prevent accidental interchange of oxygen and acetylene hoses. Do not interchange fittings on hoses or use other than standard hose fittings.

Never use ordinary wire as a binding in making up hose connections. Use binders or clamps designed for hose use.

Use only standard brass splices for splicing hose — never use copper tubing.

Avoid long lengths of hose. They tend to kink and to be mistreated. When long lengths are necessary, be sure all connections are tight.

Keep oil and grease away from hoses.

Protect hoses from sparks, hot slag, hot objects, sharp edges, and open flame.

If a hose is burned by a flashback, discard that length of hose. A flashback burns the inner walls and makes the hose unsafe.

Examine all hose periodically for leaks, worn places, and loose connections. Escaping acetylene may start a serious fire or cause severe burns.

Test for leaks by immersing the hose — under normal working pressure — in water. Repair leaks and worn places at once by cutting the hose and remaking the joint with standard fittings.

Do not try to repair hoses with tape.

SETTING UP

See that your cylinders and equipment are clean, in a safe location, in good working order and adequate for the job intended.

Be sure your gloves are not oily and that your clothing is designed to protect you properly.

Before connecting regulators to cylinders, crack the cylinder valve carefully to blow out any foreign matter that might harm seats, clog orifices, or become ignited.

Never crack an acetylene valve near other welding work, sparks, open flames or persons.

Never force connections.

Before opening the cylinder or manifold valve, make sure that the regulator is drained of gas by engaging regulator adjustment screw and allowing gas to flow out of the regulator. This will allow the high-pressure seat to open when pressurizing the regulator and will prevent excessive compression temperatures at the high-pressure seat.

After all the residual gas has been drained, completely release the adjusting screw. This will prevent the regulator from feeding gas into the line when the regulator is pressurized, until the adjusting screw is turned in.

Fig. 135 — Always Stand To One Side When Opening Cylinder Valves

Stand to One Side of the Regulator Gauge when the cylinder valve is opened (Fig. 135).

Open all cylinder valves **slowly.** When pressurizing regulator with HP gauge, particularly the oxygen regulator, open valve slightly so that HP gauge pointer moves slowly to maximum reading.

Never open an acetylene cylinder valve more than 1½ turns and preferably less than a single turn — but open oxygen cylinder valves wide. Opening acetylene cylinder valve wide is unnecessary, but opening oxygen valves wide seals the clearance around the stem and prevents leakage.

Leave valve wrench in position whenever acetylene cylinder valves are open. This will allow quick closing in an emergency.

Standard hose is not always color-coded although connections are thread-coded. Follow your connections through when setting up and make sure oxygen and acetylene lines are not interconnected.

Be sure all connections are tight. Never try to locate a leak with a flame — use soapy water.

Coil excess hose neatly so it cannot kink or tangle. Place hose so it will not be stepped on or run over and so it is clear of sparks and slag from your work.

ADJUSTING PRESSURES

Improper pressures are not only wasteful, they prevent you from doing your best work and they can be **dangerous.** Flashbacks can be caused by improper pressures.

Use manufacturer's charts as a guide to correct pressures for your job.

The use of acetylene at pressures in excess of 15 psig (103 kPa) [30 psia (206 kPa)] for welding, cutting and heating (or in pressurized chambers) is not recommended.

In adjusting oxygen pressure, first be sure that the torch acetylene valve is closed. Open the torch oxygen valve. Adjust your oxygen regulator until low-pressure gauge indicates proper pressure, while torch valve is open and oxygen is flowing through the tip. Close torch oxygen valve.

In adjusting acetylene pressure, first be sure that the torch oxygen valve is closed. Then follow same procedure as for oxygen.

OPERATING THE TORCH

Purge each hose before lighting the torch.

Fig. 136 — Light Torch with Sparklighter or Pilot Light — Don't Use Matches

Light Torch With Sparklighter or Pilot Light (Fig. 136). Don't use matches.

Never direct gas stream towards self or others. When lighting or handling torch, be careful to keep flame and sparks directed away from personnel, flammables and equipment. (See "Fire Prevention.")

Do not bring cylinders into confined spaces.

Take all precautions for ventilation, protective clothing, etc. covered in earlier sections.

BACKFIRES AND FLASHBACKS

A **backfire** is a loud noise associated with the momentary extinguishment or re-ignition of the flame at the torch tip. It may be caused by touching the tip against the work, by particles entering the tip and obstructing the gas flow, or by over-heating the tip. Sometimes the trouble will clear itself immediately and, if work is hot enough, the torch will relight automatically. If this does not happen, close oxygen torch valves immediately (cutting and then pre-heating valve). Close acetylene valve. Then relight, using standard lighting procedure which includes purging the hose lines. Before relighting, check your pressures.

A **flashback** is the burning back of the flame into the tip or torch (or the hose if an explosive mixture is present in one of the lines). It is sometimes accompanied by a hissing or squealing sound and a smoky or sharp-pointed flame. This condition requires extinguishing the flame by closing first the torch oxygen valve and then the torch acetylene valve. Then wait a few moments to be sure the fire in the torch or hose has a chance to burn out. Flashbacks can be caused by failure to purge, improper pressures, distorted or loose tips or mixer seats, kinked hose, clogged tip or torch orifices or over-heated tip or torch.

Flashbacks mean that something is radically wrong with your equipment or your handling of it. Before attempting to relight your torch, check for trouble as follows:

First of All, Did You Purge Your Lines individually before lighting? Did you check your pressures? Are they near recommended pressures? Then remove hoses from torch and inspect for damage. If the flame has burned back into the hose, cut back to undamaged portion of the hose and remake connections (with standard clamp device). Again: In setting up, be sure hose does not lay where it may be stepped on or run over. Avoid long lengths of hose. Use recommended pressures.

STOPPING WORK

Close oxygen torch valve first, then acetylene torch valve, making sure that any flame left at the tip is extinguished and the acetylene torch valve is closed tight.

Fig. 137 — Stopping Work

If oxygen torch valve is closed last, make sure acetylene torch valve is not leaking.

When shutting down for a brief interval, close torch valves only and leave the hose and torch in orderly fashion so they will not be injured or disturbed.

Never hang a torch or hose on a regulator or cylinder valve unless the cylinder and torch valves are closed, and the hose is drained of gas.

Do not crimp hose to stop flow of gases temporarily as in changing torch or tip.

When work is completed, or when leaving area for any reason, proceed after closing torch valves as follows:

1. *Close cylinder valves (Fig. 137).*
2. *Drain all oxygen from hose and regulator by opening torch oxygen valve and then closing.*
3. *Drain acetylene in the same manner.*
4. *Release regulator pressure adjusting screws.*

When shutting down for an extended period, disconnect all apparatus and store it. In this way, unauthorized personnel will not be using the equipment, and equipment will not be damaged accidentally.

Make sure cylinder valve is tightly closed before removing regulator.

Do not leave unlighted torches in confined spaces.

SAFETY IN ARC WELDING

Fig. 138 — Arc Welder at Work

Arc welding includes shielded metal-arc, gas-shielded arc and carbon-arc welding. Only general safety measures can be indicated for these areas because arc welding equipment varies considerably in size and type. Equipment may range from a small portable shielded metal-arc welder to highly mechanized production gas-shielded arc welders. In each case, follow the specific recommendations of the manufacturer.

Safety practices which are generally common to all types of arc welding operations are as follows:

1. Welding equipment should be installed according to provisions of the National Electric Code.

2. A welding machine should be equipped with a power disconnect switch which is conveniently located at or near the machine so the power can be shut off quickly.

3. Repairs to welding equipment should never be made unless the power to the machine is shut off. The high voltage used for arc welding machines can inflict severe and fatal injuries.

4. Welding machines must be properly grounded. Stray current can cause severe shock when undergrounded parts are touched.

5. Never change the polarity switch while the machine is under a load. Wait until the machine idles and the circuit is open. Otherwise, the contact surface of the switch may be burned and the resulting arcing could cause an injury.

6. Welding cables should not be overloaded or a machine operated with poor connections. Operating with currents beyond the rated cable capacity causes overheating. Poor connections may cause the cable to arc when it touches metal grounded in the welding circuit.

7. Avoid damp areas and keep the hands and clothing dry at all times. Dampness on the body may cause an electric shock.

8. Never strike an arc on a compressed gas cylinder.

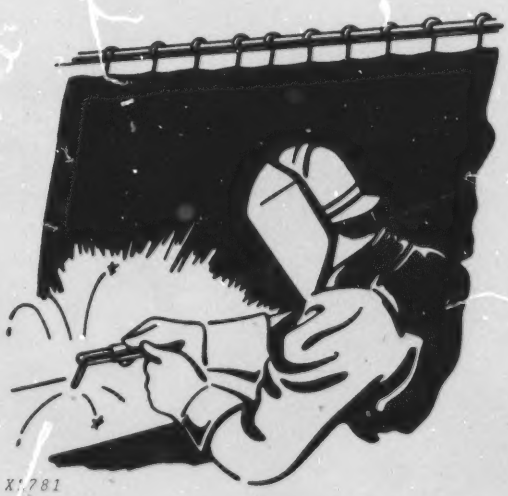


Fig. 139 — Use a Protective Screen To Protect Others From Arc Rays

9. Do not strike an arc if someone is nearby without proper eye protection. Arc rays are harmful to the eyes and skin. Use a screen to protect others (Fig. 139).

10. Press-type welding machines should be effectively guarded.

11. Suitable spark shields must be used around equipment in flash welding.

12. Keep the uninsulated portion of the electrode holder from touching the welding ground when the current is on. This will cause a flash.

13. Keep welding cables dry and free from oil and grease.

14. Never carry welding cable coiled around the shoulders when they are carrying power.

15. Observe all the general precautions on protective clothing, ventilation, and fire prevention which are outlined in the earlier part of this section.

SAFETY IN CUTTING

Fires often occur in cutting simply because precautions were not taken. Too often an operator forgets that sparks and falling slag can travel as much as 35 feet (10.5 m) and can pass through cracks out of sight of the goggled operator.

Observe these rules when cutting:

1. *Never use a cutting torch where sparks will be a hazard such as near rooms containing flammable materials, especially dipping or spraying rooms.*

2. *If you must do cutting over a wooden floor, sweep the floor clean and wet it down before starting. Use a bucket or pan containing water or sand to catch the dripping slag.*

3. *Keep a fire extinguisher nearby whenever any cutting is done.*

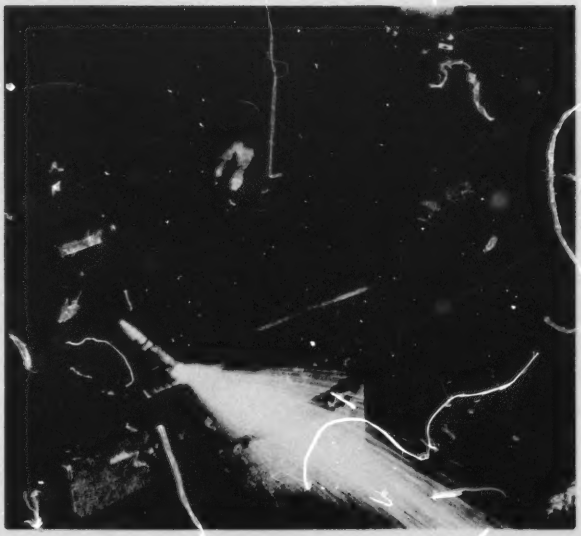


Fig. 140 — Sparks Can Be A Fire Hazard In Cutting Operations

4. *Whenever possible, do cutting in wide open areas so sparks and slag will not become lodged in crevices or cracks.*

5. *If cutting is to be done near flammable materials and the materials cannot be moved, suitable fire resisting guards must be securely installed.*

6. *In shops where there is a dirty or gassy atmosphere, take extra precautions to avoid explosions resulting from electric sparks or open fire during a cutting operation.*

FOS — 52 Litho In U.S.A.

DEFINITIONS OF TERMS AND SYMBOLS

This section explains the meaning of terms most used by welders. Technical engineering terms have been simplified.

A

AC or ALTERNATING CURRENT — Electricity which reverses its direction of electron flow regularly and periodically. The period of alternating depends upon the cycle of the current. For 60-cycle current, the current goes in one direction and then in the other direction 60 times in the same second, so the current changes its direction 120 times in one second.

ACETYLENE — Gas composed of two parts of carbon and two parts of hydrogen. When burned in an atmosphere of oxygen, it produces one of the highest flame temperatures obtainable.

ACETYLENE CYLINDER — Specially built container manufactured according to I.C.C. Standards. Used to store and ship acetylene. (Occasionally called "tank" or "bottle.")

ACETYLENE HOSE — (See Hose)

ACETYLENE REGULATOR — An automatic valve used to reduce acetylene cylinder pressures to torch pressures and to keep the pressures constant.

ALLOY — A mixture of two or more metals.

ANNEALING — Softening metals by heat treatment. This most commonly consists of heating the metals up to a critical temperature and then cooling them slowly.

ANODE — Electrical term for "positive." It is that part of an electrical circuit to which electrons are flowing.

ARC — Term given to the flow of electricity through a gaseous space or air gap. In arc welding, this flow of electricity through the air produces the high temperatures.

ARC BLOW — Tendency for an arc to wander or whip from its normal course during arc welding. It is caused by magnetic changes.

ARC CUTTING — Making a slot or kerf in a metal using energy of an electric arc.

ARC VOLTAGE — Electrical potential (pressure or voltage) across the arc.

ARC WELDING — Fusing two metals together using an electric arc as the source of heat.

AUTOMATIC WELDING — Welding in which the work, the torch, and/or the arc is mechanically moved and controls are used to control the speed and/or the direction of travel.

A.W.S. — Abbreviation for American Welding Society.

AXIS OF A WELD — An imaginary line along the center of gravity of the weld metal and perpendicular to a cross section of the weld metal.

B

BACKFIRE — A short "pop" of the torch flame followed by extinguishing of the flame or continued burning of the gases.

BACKHAND WELDING — Welding in the direction opposite the direction the gas flame is pointing.

BACKING — Some material placed on the root side of a weld to aid control of penetration.

BACK-STEP WELDING — Welding small sections of a joint in a direction opposite the direction the weld as a whole is progressing.

BACKWARD WELDING — See Backhand Welding.

BASE METAL — Metal to be welded, cut, or brazed. Also called the "work."

FOS — 52 Litho In U.S.A.

BEAD — Denotes the appearance of the finished weld; describes neatness of the ripples formed by the metal while it was in a semiliquid state.

BEVEL — Angling the metal edge where welding is to take place.

BLOWPIPE — Another term applied to the oxy-acetylene torch.

BOND — Junction of the weld metal and the base metal.

BRAZE WELDING — Making an adhesion groove, fillet or plug connection with a brazing alloy.

BRAZING — Making an adhesion connection with a minimum of alloy which melts above 800° F. and which flows by capillary between close-fitting parts.

BRONZE WELDING — See Braze Welding.

BUILDUP — Amount a weld face is extended above the surface of the metals being joined.

BURNED METAL — Term occasionally applied to the metal which has been combined with oxygen so that some of the carbon changed into carbon dioxide and some of the iron into iron oxide.

BURNING — Violent combination of oxygen with any substance which produces heat. This word is sometimes used instead of Flame Cutting.

BUTT JOINT — An assembly in which the two pieces joined are in the same plane, with the edge of one piece touching the edge of the other.

C

CABLE — See Lead.

CAPILLARY ACTION — Property of a liquid to move into small spaces if it has the ability to "wet" these surfaces.

CARBON — An element which, when combined with iron, forms various kinds of steel. In steel, it is the changing carbon content which changes the physical properties of the steel. Carbon is also used in a solid form as an electrode for arc welding, as a mold to hold weld metal, and for motor brushes.

CARBONIZING — See Carburizing or Reducing.

CARBURIZING — A carburizing flame is an oxygen-fuel gas flame with a slight excess of the fuel gas.

CASE HARDENING — Adding carbon to the surface of a mild steel object and heat treating to produce a hard surface.

CASTINGS — Metallic forms which are produced by pouring molten metal into a shaped container (mold).

CATHODE — Electrical term for "negative."

CENTIGRADE — Units of metric system temperature scale.

CHAMFERING — See Beveling.

COATED ELECTRODE — See Covered Electrode.

CONCAVE WELD FACE — A weld having the center of its face below the weld edges.

CONE — Inner visible flame shape of a neutral or near neutral flame.

CONTINUOUS WELD — Making the complete weld in one operation.

CONVEX WELD — A weld with the face above the weld edges.

CORNER JOINT — Junction formed by edges of two pieces of metal touching each other at angle of about 90 degrees.

COVERED ELECTRODE — Metal rod used in arc welding which has a covering of materials to aid in arc welding process.

CRACKING — Action of opening a valve slightly and then closing the valve immediately.

CRATER — A depression in the face of a weld, usually at the end of an arc weld.

CROWN — Curve or convex surface of finished weld proper.

CUTTING FLAME — Cutting by a rapid oxidation process at a high temperature. It is produced by a gas flame accompanied by a jet action which blows the oxides away from the cut.

CYLINDER — A container used to hold gases used in welding. See (Oxygen, Acetylene.)

D

DC or DIRECT CURRENT — Electric current which flows only in one direction.

DIRECT POLARITY — Direct current flowing from anode (base metal) to cathode (electrode). The electrode is negative and the base metal is positive.

DISTORTION — Warping of a structure.

DOWNHAND WELDING — See Flat Position Welding.

E

EDGE JOINT — Joint formed when two pieces of metal are lapped with at least one edge of each at an edge of the other.

ELECTRODE — A substance which brings electricity up to the point where the arc is to be formed; in other words it is the material immediately adjacent to the arc proper and the one which carries the current to this point. In electric arc welding the electrode is usually melted and becomes a part of the weld.

ELONGATION — Percentage increase in the length of a specimen when stressed to its yield strength.

EROSION — Reducing in size of an object because of a liquid or gas impact on the object.

EUTECTIC ALLOY — A mixture of metals which has a melting point lower than that of any of the metals in the mixture, or of any other mixture of these metals.

F

FACE OF WELD — The exposed surface of the weld.

FAHRENHEIT — A temperature scale used in most English speaking countries in the industrial and engineering areas. Symbol is F. (as in 72°F.)

FILLER ROD — Metal wire that is melted and added to the welding puddle to produce the necessary increase in bead thickness. (See Welding Rod.)

FILLET — Weld metal in the internal vertex, or corner, of the angle formed by two pieces of metal, giving the joint additional strength to withstand unusual stresses.

FILLET WELD — Metal fused into a corner formed by two pieces of metal whose welded surfaces are approximately 90 degrees to each other.

FLAME CUTTING — Cutting performed by an oxygen-fuel gas torch flame which has an oxygen jet.

FLASH — Impact of electric arc rays against the human eye. Also the fin of surplus metal formed at the seam of a resistance weld.

FLAT POSITION — A horizontal weld on the upper side of a horizontal surface.

FLUX — A chemical used to promote fusion of metals during the welding process.

FORGING — Metallic shapes being derived by either hammering or squeezing the original piece of metal into the desired shapes or thicknesses.

FOREHAND WELDING — Fusing metal in the same direction as the torch flame points.

FUSION — Intimate mixing of molten metals.

G

GAS METAL-ARC WELDING — Welding using a continuously fed consumable electrode and a shielding gas.

GAS POCKETS — Cavities in weld metal caused by entrapped gas.

GAS TUNGSTEN-ARC WELDING — Welding using a tungsten electrode and a shielding gas.

GENERATOR — A mechanism which generates or produces some substance, i.e., electric generator, acetylene generator.

GOUGING — Cutting of a groove in the surface of a metal using the gas cutting torch of an arc-air cutting outfit.

GROOVE WELD — A welding rod fused into a joint which has the base metal removed to form a V, U, or J trough at the edge of the metals to be joined.

H

HAND SHIELD — See Shield.

HEAT — Molecular energy of motion.

HEAT-AFFECTED ZONE — That part of the base metal which has been altered by the heat from the welding, brazing or cutting operation.

HEAT CONDUCTIVITY — Speed and efficiency of heat energy movement through a substance.

HELMET — A protecting hood which fits over the arc welder's head, provided with a lens of safety glass through which the operator may safely observe the electric arc.

FOS — 52 Litho in U.S.A.

HORIZONTAL POSITION — A weld performed on a horizontal seam at least partially on a vertical surface.

HOSE — Flexible medium used to carry gases from regulator to the torch. It is made of fabric and rubber.

HYDROGEN — A gas formed of the single element hydrogen. It is considered one of the most active gases. When combined with oxygen, it forms a very clean flame, which, however, does not produce very much heat.

I

INERT GAS ARC WELDING — Surrounding the arc with a gas which does not react with the electrode and base metal and keeps the atmosphere away from the arc.

INFRARED RAYS — Heat rays which emanate from both the arc and the welding flame.

INSIDE CORNER WELD — Two metals fused together; one metal is held 90 degrees to the other. The fusion is performed inside the vertex of the angle.

INTERMITTENT WELD — Joining two pieces and leaving unwelded sections in the joint.

J

JOINT — Where two pieces meet when a structure is made of smaller pieces.

L

LAP JOINT — A joint in which the edges of the two metals to be joined overlap one another.

LAYER — A certain weld metal thickness made of one or more passes.

LEAD WIRE — Electric wire from the power source to the electrode holder or to the ground clamps.

LEG OF FILLET WELD — Distance from point where the base metals touched to toe of the fillet.

LENS — A specially treated glass through which a welder may look at an intense flame without being injured by the harmful rays, or glare, radiating from this flame.

M

MALLEABLE CASTINGS — Cast forms of metal which have been heat-treated to reduce their brittleness.

MAPP — A stabilized methyl acetylene-propadiene fuel gas. It is a Dow Chemical Co. product.

MIG — A term used to describe gas metal arc welding (metal inert gas).

MIXING CHAMBER — That part of the welding torch where the welding gases are intimately mixed, prior to combustion.

N

NEGATIVE CONNECTIONS — Connections in an electric circuit through which the current flows back to its source.

NEUTRAL FLAME — Flame which results from combustion of perfect proportions of oxygen and the welding gas. Used for most welding jobs.

NOZZLE — See Tip.

O

ORIFICE — Opening through which gases flow. It is usually the final opening, or any opening controlled by a valve.

OUTSIDE CORNER WELD — Fusing two pieces of metal together, with the fusion taking place on the underpart of the seam.

OVERHEAD POSITION — A weld made on the underside of the joint with the face of the weld in a horizontal plane.

OVERLAP — Extension of the weld face metal beyond the toe of the weld.

OXIDIZING — Combining oxygen with any other substance. For example, a metal is oxidized when the metal is burned, i. e., oxygen is combined with all the metal or parts of it.

OXIDIZING FLAME — Flame produced by an excess of oxygen in the torch mixture, leaving some free oxygen which tends to burn the molten metal.

OXY-ACETYLENE WELDING — See Oxygen-Acetylene Welding.

OXYGEN — A gas formed of the element oxygen. When it very actively supports combustion it is called burning; when it slowly combines with a substance it is called oxidation.

OXYGEN-ACETYLENE CUTTING — Cutting metal using the oxygen jet which is added to an oxygen-acetylene preheating flame.

OXYGEN-ACETYLENE WELDING — A method of welding which uses a fuel combination of two gases — oxygen and acetylene.

OXYGEN CYLINDER — A specially-built container manufactured according to I.C.C. standards and used to store and ship oxygen.

OXYGEN-HYDROGEN FLAME — The chemical combining of oxygen with the fuel gas hydrogen.

OXYGEN HOSE — See Hose.

OXYGEN-LP GAS FLAME — Chemical combining of oxygen with the fuel gas LP (liquefied petroleum).

OXYGEN REGULATOR — An automatic valve used to reduce cylinder pressures to torch pressures and to keep the pressures constant. They are never to be used as acetylene regulators.

P

PASS — Weld metal created by one progression along the weld.

PENETRATION — Depth of fusion into the base metal as measured from the surface of the base metal.

PLASMA — Temporary physical condition of a gas after is has been exposed to and has reacted to an electric arc.

PLUG WELD — Weld which holds two pieces of metal together; made in a hole in one piece of metal which is lapped over the other piece.

POROSITY — Presence of gas pockets or voids in the metal.

POSITIVE CONNECTIONS — Connections in an electric circuit out of which electricity constantly flows.

POSTHEATING — Temperature to which a metal is heated **after** an operation has been performed on the metal (welding, cutting, forming, etc.).

PREHEATING — Temperature to which a metal is heated **before** an operation is performed on the metal (welding, cutting, forming, etc.).

PUDDLE — Portion of a weld that is molten at the place the heat is supplied.

R

RADIOGRAPH — A photograph obtained by passing X-rays or gamma rays through the object to be photographed and recording the variations in density on a photographic film.

RAYS — (See Infrared and Ultraviolet.)

REDUCING FLAME — An oxygen-fuel gas flame with a slight excess of fuel gas.

REGULATORS — See Acetylene, Oxygen.

REINFORCEMENT of WELD — Excess metal on the face of a weld.

RESISTANCE WELDING — Welding metals using the resistance of the metals to the flow of electricity, as the source of heat.

REVERSED POLARITY — (Electrode positive-anode) referring to DC and causing electrons to flow from the base metal to the electrode.

ROOT of WELD — That part of a weld farthest from the application of weld heat and/or filler metal side.

ROSETTE WELD — See Plug Weld.

S

SHIELD — An eye and face protector held in the hand. It enables a person to look directly at the electric arc through a special lens without being harmed.

SHIELDED ARC — A form of electric welding in which a heavy flux-coated electrode is used.

SHORT ARC — A gas metal-arc process which uses a low arc voltage, where the arc is continuously interrupted as the molten electrode metal bridges the arc gap.

SIGMA WELDING — See Gas Metal-Arc Welding.

SLAG INCLUSIONS — Non-fused, non-metallic substances in the weld metal.

SOLDERING — Means of fastening metals together by adhering another metal to the two pieces of these metals. The joining metal **only** is melted during the operation. The joining metal melts below 800°F (427°C).

SPRAY ARC — Gas metal arc process which has an arc voltage high enough to continuously trans-

fer the electrode metal across the arc in small globules.

STRAIGHT POLARITY — (Electrode negative-cathode) connecting DC to cause electrons to flow from the electrode to the base metal.

STRAIN — Reaction of an object to a stress.

STRESS — Load imposed on an object.

STRESS RELIEVING — Even heating of a structure to a temperature below the critical temperature followed by a slow, even cooling.

T

TACK WELD — Small weld used to temporarily hold together components of an assembly.

TANK — See Cylinder.

T-JOINT — Joint formed by placing one metal against another at an angle of 90 degrees. The edge of one metal contacts the surface of the other metal.

TENSILE STRENGTH — Maximum pull stress in psi which a specimen is capable of developing.

THROAT of a FILLET WELD (actual throat) — Distance from the weld root to the weld face.

TIG — Term used to describe gas tungsten arc welding (tungsten inert gas).

TINNING — Term applied to soldering where the metals to be soldered together are first given a coating of the soldering metal.

TIP — Part of the torch at the end where the gas burns, producing the high-temperature flame. In resistance welding, the electrode ends are sometimes called tips.

TOE of WELD — Junction of the face of the weld and the base metal.

TORCH — The mechanism which the operator holds during gas welding and cutting, at the end of which the gases are burned to perform the various gas welding and cutting operations.

U

ULTRAVIOLET RAYS — Energy waves that emanate from the electrodes and the welding flames.

UNDERCUT — A depression at the toe of the weld which is below the surface of the base metal.

V

VERTICAL POSITION — Type of weld where the welding is done on a vertical seam and on a vertical surface.

W

WELDING — Art of fastening metals together by means of interfusing the metals.

WELD METAL — Fused portion of base metal or fused portion of the base metal and the filler metal.

WELDING ROD — Wire which is melted into the weld metal.

WELDING SEQUENCE — Order in which the component parts of a structure are welded.

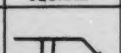
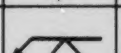
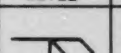
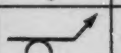
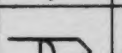
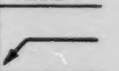
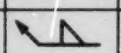
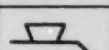
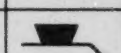
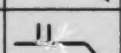
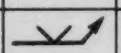
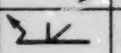
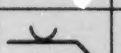
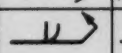
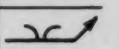
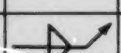
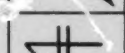
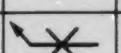
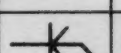
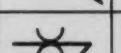
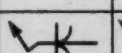
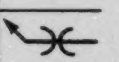
WELDMENT — Assembly of component parts joined together by welding.

Y

YIELD STRENGTH — Stress in psi at which a weld specimen assumes a specified limiting permanent set.

WELDING SYMBOLS

Basic Weld Symbols and Their Location Significance

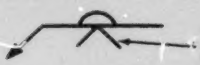
LOCATION SIGNIFICANCE	ARC AND GAS WELD SYMBOLS								
				GROOVE					
	FILLET	PLUG OR SLOT	ARC SEAM OR ARC SPOT	SQUARE	V	BEVEL	U	J	FLARE V
ARROW SIDE									
OTHER SIDE									
BOTH SIDES		Not Used	Not Used						
NO ARROW SIDE OR OTHER SIDE SIGNIFICANCE	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used

Supplementary Symbols

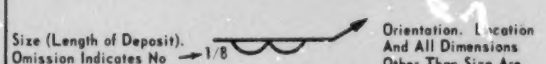
WELD ALL AROUND	FIELD WELD	CONTOUR	
		FLUSH	CONVEX

Typical Welding Symbols

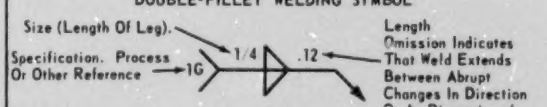
BACK OR BACKING WELD SYMBOL



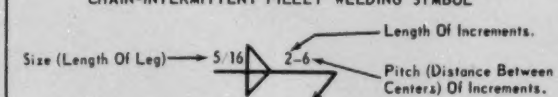
SURFACE WELD SYMBOL INDICATING BUILT-UP SURFACE


Size (Length of Deposit).
Omission Indicates No Specific Height Desired.
1/8
Orientation. Location And All Dimensions Other Than Size Are Shown On The Drawing

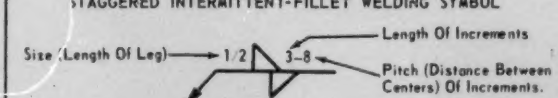
DOUBLE-FILLET WELDING SYMBOL


Size (Length Of Leg).
Specification. Process Or Other Reference
1G
1/4
.12
Length Omission Indicates That Weld Extends Between Abrupt Changes In Direction Or As Dimensioned

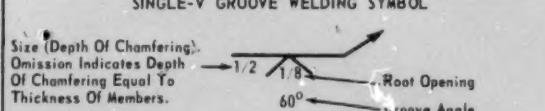
CHAIN-INTERMITTENT FILLET WELDING SYMBOL



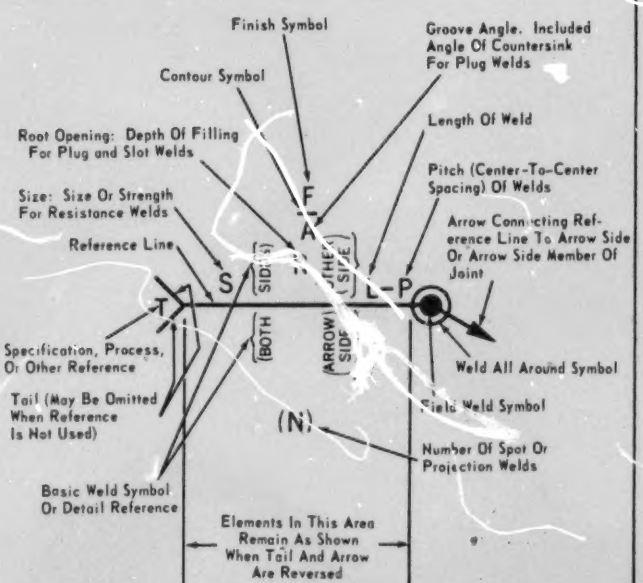
STAGGERED INTERMITTENT-FILLET WELDING SYMBOL



SINGLE-V GROOVE WELDING SYMBOL

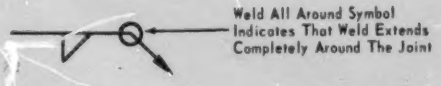


Location of Elements of a Welding Symbol


Finish Symbol
Groove Angle. Included Angle Of Countersink For Plug Welds
Contour Symbol
Length Of Weld
Root Opening: Depth Of Filling For Plug and Slot Welds
Pitch (Center-To-Center Spacing) Of Welds
Size: Size Or Strength For Resistance Welds
Arrow Connecting Reference Line To Arrow Side Or Arrow Side Member Of Joint
Reference Line
F
A
S
L-P
(BOTH SIDES)
(ARROW SIDE)
(OTHER SIDE)
Specification, Process, Or Other Reference
Tail (May Be Omitted When Reference Is Not Used)
Weld All Around Symbol
Field Weld Symbol
(N)
Number Of Spot Or Projection Welds
Basic Weld Symbol Or Detail Reference
Elements In This Area Remain As Shown When Tail And Arrow Are Reversed

Supplementary Symbols Used with Welding Symbols

WELD ALL-AROUND SYMBOL



FIELD WELD SYMBOL

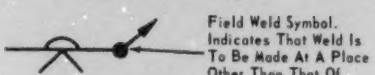


Fig. 141 — Basic Welding Symbols (American Welding Society)

ANSWERS TO PART 1 QUESTIONS

1. Because it is a **slower** method of welding than the electric processes.

2. The **inner** stage is the actual flame for welding, while the **outer** stage is a protective shield to prevent air from contaminating the molten puddle.

3. To prevent dangerous gas pressures in case of overheating. (The gas can drain slowly through the safety device in these cases).

4. a — 3; b — 2; c — 1.

5. Hold the torch at a 45 degree angle.

6. In **forehand** welding, the torch is pointed forward and the rod precedes the flame. In **backhand** welding, the torch points back toward the deposited weld and the filler rod is held between the flame and the weld.

7. Backhand technique.

8. To release all pressure from the hose and regulator.

ANSWERS TO PART 2 QUESTIONS

1. Because the demand for electrical current **varies so much** during arc welding.

2. This means that the power supply can deliver its rated load six minutes out of every ten minutes. (In manual welding, current is not needed continuously because of pauses to change electrodes, adjust work, etc.)

3. In a **straight** polarity circuit, the flow is from the electrode to the work. With **reverse** polarity, the flow is from the work to the electrode.

4. **Straight** polarity gives more heat on the work piece.

5. Arc blow is a wandering of the arc when welding in corners by large coated electrodes. It is caused by direct current creating a magnetic field.

6. Rectifiers provide a **choice** of welding currents because they can convert A.C. current to D.C. current.

7. Because electric arcs give off ultraviolet and infrared rays which are dangerous to the eyes.

8. A wide, splattered, irregular weld.

9. The **tapping** method is a rapid up-and-down motion. The **scratching** method is done with a quick scratching motion.

10. True.

ANSWERS TO PART 3 QUESTIONS

1. The reaction of metal to **oxidation,** which decomposes it.

2. First blank—"gas." Second blank—"oxygen."

3. **Drag** is the distance from the point where the oxygen stream enters the top of the metal and the point where slag emerges from the bottom of the cut.

4. The edges of the cut will melt and the cut will look ragged.

5. Cutting several metal plates at one time while they are stacked together.

6. It leaves a very rough, ragged edge.

7. Because the plasma-arc is much hotter and more velocity is possible.

ANSWERS TO PART 4 QUESTIONS

1. The metals to be joined are *not* melted in brazing, while they are in fusion welding.

2. Because in brazing there is less danger of destroying the properties of the base metal.

3. To eliminate oxides from the surface of the base metals (which could prevent a good bond).

4. Torch heating, furnace heating, induction heating.

5. *Two* carbon electrodes are used with AC units, while only *one* is used with DC units.

6. Braze welding uses a *deposited bead* at the joint instead of the thin bond in regular brazing.

7. Either (a) or (b): (a) Soldering is *not* recommended for joints which must be very strong. (b) Soldering should not be used where temperatures may approach the melting point of solder.

8. "Tin" and "lead."

9. It supplies a uniform heat.

10. Coating the copper with a thin coat of solder.

11. In *sweat* soldering, two surfaces are soldered without the solder being visible. In *seam* soldering, a larger layer of solder is run along the outside edge of a joint.

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ANSWERS TO PART 5 QUESTIONS

1. *Surfacing* is a process of metal *fusion* (like welding) which surfaces a metal. *Metallizing* is the spray coating of a surface with metal particles.

2. Abrasion, impact, corrosion.

3. These metals can be annealed to reduce their hardness, or they can be treated by preheating and post-cooling gradually.

4. The arc process is much *faster* for depositing metal.

5. Amperage should be as *low* as possible.

6. The arc should be medium *long*.

7. The particles adhere because they are partly *melted* and are sprayed under *pressure*.

8. The surface must be *cleaned* and it must be *roughened*.

ANSWERS TO PART 6 QUESTIONS

1. (Any three of these.) a. Flexibility. b. Stronger but lighter. c. Stiffer. d. Less cracking. e. Less investment in equipment. f. Freedom of design. g. Resistance to shock.

2. For correct examples, see Figs. 97, 98, and 99.

3. The V-type butt joint is best for joining heavier metals (because it allows more strength in the weld).

4. Welds which are **transverse** to lines of stress.

5. Welds should be **spaced apart** (for greater strength).

6. ¾.

7. a — 4; b — 2; c — 3; d — 1.

8. *Skip welding* is the welding of short strips along the joint, then returning to fill in the openings. It is used to reduce the heat input in the base metal (preventing residual stress).

ANSWERS TO PART 7 QUESTIONS

1. **Ferrous** and **nonferrous** types. (The ferrous are the irons and iron alloys.)

2. Mild steel.

3. Iron is a refined iron ore, while steel is a refined iron plus an alloy of carbon and other substances.

4. a-2; b-4; c-5; d-1; e-3.

5. Mild steel.

6. False! Annealing is the **softening** of metals by a refining or heat treatment.

7. Malleable iron is cast iron which has been heat treated to make it more ductile (and more resistant to shock.)

8. It loses its malleable qualities. (For this reason, malleable iron should never be welded — only brazed or braze welded.)

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